[[1]](#footnote-1)

Versatile Acoustic Shadow Detection from Scanline Statistics of Brightness-Mode and Radiofrequency Ultrasound Images

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*An acoustic shadow is an ultrasound imaging artefact which results in a continuous dark region beyond a boundary between two materials of significant impedance difference. Identifying acoustic shadows is clinical important as a shadow can indicate features such as calcifications, poor transducer contact, or lesions. Shadows also obscure anatomy beyond the shadowing boundary and increase the difficulty in interpreting ultrasound images. With the emergence of highly accessible ultrasound devices, point-of-care imaging, and large scale image processing, there is a motivation for the automated detection of an acoustic shadow.*

# INTRODUCTION

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LTRASOUD is a popular imaging modality as it provides real-time imaging, is relatively low cost compared to computed tomography of magnetic resonance imaging, and does not produce ionizing radiation. Recently, ultrasound devices have become increasingly affordable and portable [1], encouraging novice users or point-of-care ultrasound to be adopted more frequently [2-6]. However, ultrasound is susceptible to unique imaging artefacts that may cause the interpretation of images may be difficult, particularly for novice users. One such artefact is an acoustic shadow. An acoustic shadow occurs when an ultrasound wave from a transducer surface propagates towards a boundary of two materials with significantly different wave impedance properties [7]. The ultrasound wave is then mostly reflected, resulting in a loss of signal beyond the boundary. On an ultrasound brightness-mode (B-Mode) image, this appears as a sudden dark region at all depths beyond the boundary. Acoustic shadows are significant as they are an asset and detriment in ultrasound imaging. Acoustic shadows are known to occur at air-tissue [8] , tissue-bone [9, 10], and tissue-lesion [11] interface. By observing an acoustic shadow, we can deduce the presence of an air gap due to bad transducer contact, gallstones in the gallbladder, or lesions depending on the context of the imaging location. However, acoustic shadows prevent the visualization of anatomical detail of regions axially deeper than the boundary, increasing the difficulty of interpreting images. Thus, the identification of shadows is important for understanding ultrasound images.

The interpretation of acoustic shadows is commonly performed by manual inspection from an expert, such as a radiologist. However, there are several motivations for the automatic detection of acoustic shadows. First, users with less sonography experience could interpret ultrasound imagery easier with acoustic shadows automatically identified. Secondly, acoustic shadows limit the capability of automated image processing. Modern analysis techniques involving images with shadows such as 3D reconstruction [12], fiducial registration [13], and training of supervised learning algorithms [14] require features to be identified or flagged as a shadow, which is time consuming if done manually.

There are several existing techniques to automatically detect shadows which all report a high Dice similarity coefficient when compared to the gold standard of manual shadow detection [15-20]. However, existing techniques require several manually tuned parameters for different ultrasound machines, transducer geometries, and anatomy. As there exists a strong motivation to increase the usability of ultrasound for novice users, a shadow detection method with minimal configuration that requires knowledge of ultrasound machine properties is desired.

We present shadow detection methods based on analysis of scanline statistics from either radiofrequency (RF) and B-Mode data that requires only the transducer pulse width as an input parameter. The detection method was designed to detect shadows from multiple anatomical locations, depths, and transducers.

# Existing Work

## Pixel Intensity Methods

## Geometric Methods

## Learning Methods

Number equations consecutively with equation numbers in parentheses flush with the right margin, as in (1). First use the equation editor to create the equation. Then select the “Equation” markup style. Press the tab key and write the equation number in parentheses. To make your equations more compact, you may use the solidus ( / ), the exp function, or appropriate exponents. Use parentheses to avoid ambiguities in denominators. Punctuate equations when they are part of a sentence, as in

 (1)

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# Methods

To detect acoustic shadows, the statistics of a local patch along a scanline is analyzed. If RF data is available, then the RF data is processed with statistical analysis based on the acoustic physics of shadows. The RF data is the raw signal read by the transducer and is representative of the interactions between the acoustic wave and a shadow boundary. However, many ultrasound machines do not provide access to the RF data, which is difficult to visualize on a graphic image and rather provide only B-Mode data. The machines process the RF data with several nonlinear transformations and filtering to produce an enhanced image for visual interpretation by a clinician. This process obscures many features from the RF signal in favor of visual enhancement, such as by smoothing the grainy patches seen in an RF image. However, these features contain information on how the ultrasound signal interacts with the material and can be leveraged to characterize material properties, such as the presence of tissue. In addition, the B-Mode image can be manually enhanced by adjusting parameters such as gain or dynamic range windowing and B-Mode images are subject to operator variability. Thus, we argue that analyzing features such as acoustic shadows from the RF data provides a more consistent and versatile detection.

We also present a scanline statistical analysis on B-Mode data of the same RF data set. This is to provide a shadow detection method in the common scenario where RF data is not available. Both detection methods do not require significant configuration between different imaging scenarios, other than adjusting the window of the scanline patch to correspond to the transducer pulse width.

## Data Collection

Ultrasound B-Mode and RF data was acquired by scanning X adult participants with informed written consent. Each patient was scan on the forearm near the distal end of the pronator quadratus in the supinated position, on the elbow near the cubital fossa in the supinated position, and on the anterior surface of right ribs 11-12 in a laid down position. The scans were taken with a curvilinear (C-5-2/60, Ultrasonix, Canada) and a linear (L14-5/38, Ultrasonix, Canada) transducer for a total of 6 images per participant. The B-Mode and RF data were then processed by our algorithm to identify regions of acoustic shadowing.

## Validation

A trained annotator manually outlined regions of acoustic shadow on the B-Mode images. The manually identified shadow regions were used as a gold standard, as manually identifying shadows is common clinical practice and has been used in previous literature for comparison [16]. The pixels of the manually identified shadows were compared with that of the automatically detected shadows to obtain a Dice coefficient to quantify the performance of the detection.

 (1)

TABLE I

Definitions of Similarity Variables

|  |  |  |  |
| --- | --- | --- | --- |
|  | | Pixel Manually Labelled by Annotator | |
| Shadow | Non-Shadow |
| Pixel Automated Labelled by Algorithm | Shadow | True Positive (TP) | False Positive (FP) |
| Non-Shadow | False Negative (FN) | True Negative (TN) |

## Radiofrequency Speckle Analysis

To detect shadow regions on the RF data, ultrasonic speckle is analyzed to characterize patches of the image. Speckle occurs due to the scattering of acoustic waves in a material, which results in a series of interference patterns that can be modelled by a wave packet. B-Mode data commonly attempts to remove speckle from the image for a smoother visualization, but speckle contains information of the acoustic interactions of the material. An acoustic wave scatters differently depending on the material with a different speckle pattern and thus, it is possible to characterize material by analyzing speckle. There are several models used in previous literature to model the distribution of the speckle. \_\_\_\_ et al. analyzed speckle to . The Nakagami distribution was chosen as is provides more generality compared to the Rayleigh distribution and is computationally efficient compared to the homodyned K-distribution.

The RF data for each scan was processed by computing the absolute Hilbert transform of each scanline and converted to a logarithmic scale. The processed RF data then roughly resembles the B-Mode data, but with speckle artefacts present. Each scanline was then segmented into overlapped patches with a width of a single RF data point and a length of three times the pulse width of the transducer. The patch size was chosen from effective patch sizes in previous literature to analyze speckle.

A maximum likelihood estimate (MLE) was computed to fit a Nakagami distribution on each patch to assign each patch with a Nakagami shape and scale parameter to characterize the speckle in each patch.

For the purpose of identifying a shadow or non-shadow region, a simple thresholding scheme is sufficient. Non-shadow regions contain significant speckle whereas shadow regions contain little speckle due to the lack of signal in shadow regions. There still remains slight speckle in shadow regions due to other imaging artefacts that scatter acoustic waves in the shadow region, but the speckle is likely minimal.

To characterize the shadow and non-shadow regions in the RF image, Otsu’s method was applied to compute a threshold for the Nakagami shape and scale parameter. The data points of the RF image are then flagged as potential shadow if the patch for which the point is centered on has a Nakagami shape and scale parameter less than the threshold.

# Some Common Mistakes

The word “data” is plural, not singular. The subscript for the permeability of vacuum µ0 is zero, not a lowercase letter “o.” The term for residual magnetization is “remanence”; the adjective is “remanent”; do not write “remnance” or “remnant.” Use the word “micrometer” instead of “micron.” A graph within a graph is an “inset,” not an “insert.” The word “alternatively” is preferred to the word “alternately” (unless you really mean something that alternates). Use the word “whereas” instead of “while” (unless you are referring to simultaneous events). Do not use the word “essentially” to mean “approximately” or “effectively.” Do not use the word “issue” as a euphemism for “problem.” When compositions are not specified, separate chemical symbols by en-dashes; for example, “NiMn” indicates the intermetallic compound Ni0.5Mn0.5 whereas “Ni–Mn” indicates an alloy of some composition NixMn1-x.

Be aware of the different meanings of the homophones “affect” (usually a verb) and “effect” (usually a noun), “complement” and “compliment,” “discreet” and “discrete,” “principal” (e.g., “principal investigator”) and “principle” (e.g., “principle of measurement”). Do not confuse “imply” and “infer.”

Prefixes such as “non,” “sub,” “micro,” “multi,” and “ultra” are not independent words; they should be joined to the words they modify, usually without a hyphen. There is no period after the “et” in the Latin abbreviation “*et al.*” (it is also italicized). The abbreviation “i.e.,” means “that is,” and the abbreviation “e.g.,” means “for example” (these abbreviations are not italicized).

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Fig. 1. Magnetization as a function of applied field. Note that “Fig.” is abbreviated. There is a period after the figure number, followed by two spaces. It is good practice to explain the significance of the figure in the caption.

TABLE I

Units for Magnetic Properties

|  |  |  |
| --- | --- | --- |
| Symbol | Quantity | Conversion from Gaussian and  CGS EMU to SI a |
| Φ | magnetic flux | 1 Mx → 10−8 Wb = 10−8 V·s |
| *B* | magnetic flux density,  magnetic induction | 1 G → 10−4 T = 10−4 Wb/m2 |
| *H* | magnetic field strength | 1 Oe → 103/(4π) A/m |
| *m* | magnetic moment | 1 erg/G = 1 emu  → 10−3 A·m2 = 10−3 J/T |
| *M* | magnetization | 1 erg/(G·cm3) = 1 emu/cm3  → 103 A/m |
| 4π*M* | magnetization | 1 G → 103/(4π) A/m |
| σ | specific magnetization | 1 erg/(G·g) = 1 emu/g → 1 A·m2/kg |
| *j* | magnetic dipole  moment | 1 erg/G = 1 emu  → 4π × 10−10 Wb·m |
| *J* | magnetic polarization | 1 erg/(G·cm3) = 1 emu/cm3  → 4π × 10−4 T |
| χ*,* κ | susceptibility | 1 → 4π |
| χρ | mass susceptibility | 1 cm3/g → 4π × 10−3 m3/kg |
| μ | permeability | 1 → 4π × 10−7 H/m  = 4π × 10−7 Wb/(A·m) |
| μr | relative permeability | μ → μr |
| *w, W* | energy density | 1 erg/cm3 → 10−1 J/m3 |
| *N, D* | demagnetizing factor | 1 → 1/(4π) |

Vertical lines are optional in tables. Statements that serve as captions for the entire table do not need footnote letters.

aGaussian units are the same as cg emu for magnetostatics; Mx = maxwell, G = gauss, Oe = oersted; Wb = weber, V = volt, s = second, T = tesla, m = meter, A = ampere, J = joule, kg = kilogram, H = henry.

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### Figures that are meant to appear in color, or shades of black/gray. Such figures may include photographs, illustrations, multicolor graphs, and flowcharts.

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### Figures that are composed of only black lines and shapes. These figures should have no shades or half-tones of gray. Only black and white.

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### Head and shoulders shots of authors which appear at the end of papers. Not allowed for papers in TMI.

### *Tables* Data charts which are typically black and white, but sometimes include color.

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The term color space refers to the entire sum of colors that can be represented within the said medium. For our purposes, the three main color spaces are Grayscale, RGB (red/green/blue) and CMYK (cyan/magenta/yellow/black). RGB is generally used with on-screen graphics, whereas CMYK is used for printing purposes.

All color figures should be generated in RGB or CMYK color space. Grayscale images should be submitted in Grayscale color space. Lineart may be provided in grayscale OR bitmap color space. Note that “bitmap color space” and “bitmap file format” are not the same thing. When bitmap color space is selected, .TIF/.TIFF is the recommended file format.

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Figure axis labels are often a source of confusion. Use words rather than symbols. As an example, write the quantity “Magnetization,” or “Magnetization *M*,” not just “*M*.” Put units in parentheses. Do not label axes only with units. As in Fig. 1, for example, write “Magnetization (A/m)” or “Magnetization (Am−1),” not just “A/m.” Do not label axes with a ratio of quantities and units. For example, write “Temperature (K),” not “Temperature/K.”

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Figures (lineart or photograph) should be named starting with the first 5 letters of the corresponding author’s last name. The next characters in the filename should be the number that represents the sequential location of this image in your article. For example, in author “Anderson’s” paper, the first three figures would be named ander1.tif, ander2.tif, and ander3.ps.

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