Medical ultrasound simulation guide (supplementary document)

Overview

Utilizing the k-Wave acoustics toolbox in MATLAB, researchers at the Penn State BioPhotonics and Ultrasound Imaging Lab have created a code-base for accurate medical ultrasound imaging simulation. The primary use case anticipated for these codes will be the ability to create large amounts of realistic medical ultrasound images to be used for training deep learning algorithms, such as object recognition/segmentation or speckle noise reduction algorithms.

Through extensive testing, the codes can accurately simulate up to 12 distinct tissue contrast levels, as seen in the contrast level dictionary provided below.

The codes come in 2 parts: a phantom acoustic characteristics script and an ultrasound simulation script. The phantom acoustic characteristics script provided applies acoustic characteristics to an in-silico phantom. Users are free to modify this script as necessary or substitute it for a phantom characteristic script/tool of their own. The simulation script can be modified as needed, but will run as-is if provided a density map and sound speed map of the desired phantom (which is originally provided from the phantom characteristic script).

The k-Wave acoustics toolbox is necessary to utilize these simulation codes.

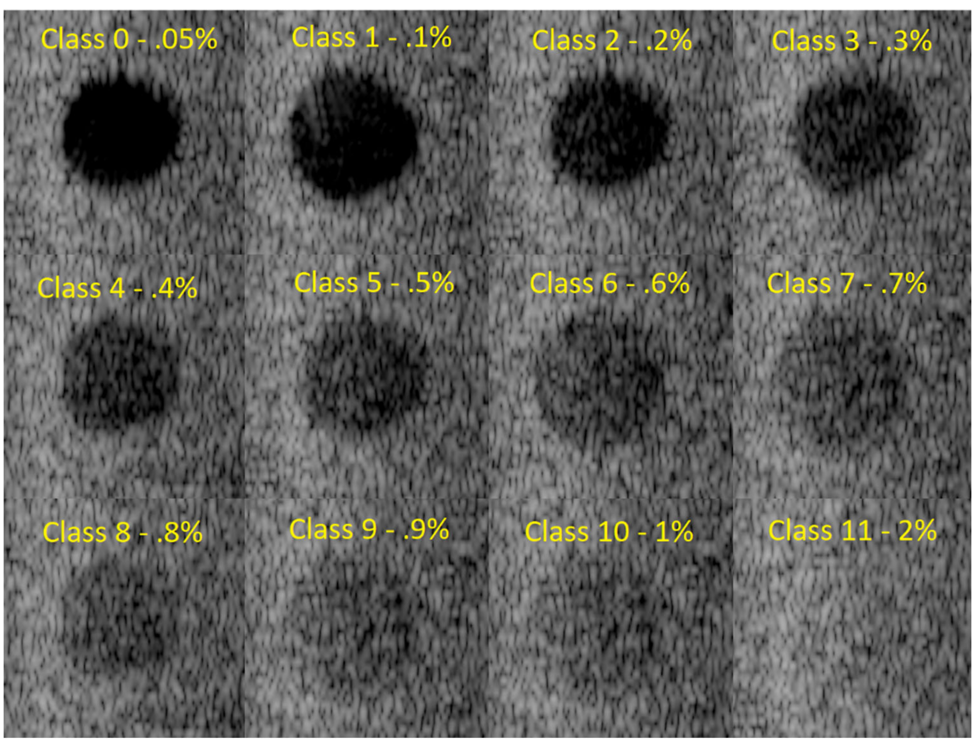

Fig. 1) Tissue Contrast Level Dictionary

Phantom Acoustic Characteristics script (phantom_acoustic_characteristics.m)

The existing acoustic phantom characteristics script assumes a quantized in-silico phantom (created in MS Paint, Adobe Photoshop, etc.), in which each tissue class (prostate, bladder, rectum, etc.) is represented by an individual 8-bit pixel intensity. The user will input this in-silico phantom.

The 12 tissue contrast levels form a contrast level "dictionary" (Fig. 1, prev. page), and are pre-loaded into the script. Users will select their desired contrast level for each tissue class from the dictionary. For clarification, this means that if a user wants, for example, a simulated prostate tissue to appear like the class/level 3 target in the contrast dictionary, they will select class/level 3 contrast for the prostate tissue class. The contrast levels are then applied to the density map for the given tissue class. Applying the contrast level to the density map of the tissue class will provide the acoustic heterogeneity necessary to produce an accurate medical ultrasound simulation. Each contrast level has an associated "percent heterogeneity", for example: level 0/class 0 has 0.05% heterogeneity. This means that for a tissue class with contrast level 0 applied, the density map of that specific tissue class will have .05% heterogeneity. During this process of assigning contrast users will also define the sound speed and density for each tissue class.

The output of the acoustic characteristics script will be a density map, which shows the tissue density at each point. in the phantom, and a sound speed map, which shows the tissue sound speed of each point in the phantom.

The density and sound speed maps will be used in the ultrasound simulation script to calculate acoustic impedance and create the ultrasound image of the in-silico phantom.

As stated above the characteristic code is free to be modified as needed or omitted entirely in favor of any script/tool the user desires, as long the modified/new script creates a density and sound speed map.

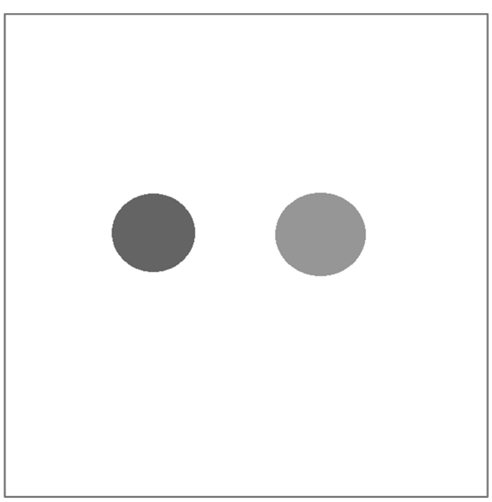

Fig. 2) Example phantom, pixel intensities: left target = 100, right target = 150, background = 255

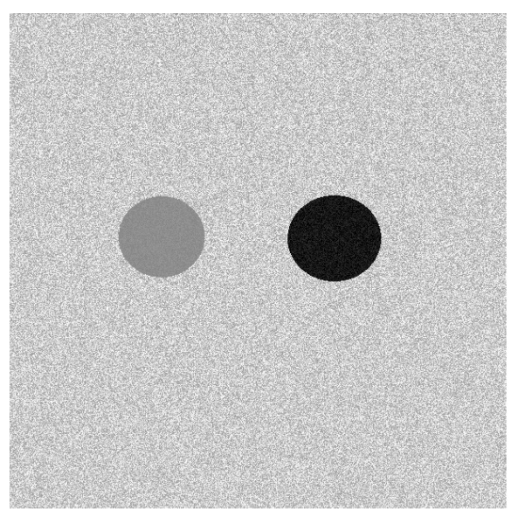

Fig. 3) Density Map. Left Target: contrast level 4, 0.4% density heterogeneity. Right Target: contrast level 10, 1% density heterogeneity. Background: contrast level 11, 2% density heterogeneity.

Ultrasound simulation script (ultrasound_simulation_code.m)

The simulation script requires the density map and sound speed map mentioned previously. Again, these can either be generated from the given phantom acoustic characteristics script, or can be generated from another tool/script the user desires to use.

The density and sound speed maps are automatically loaded into the simulation script. They are then used to calculate acoustic impedances, which are then applied into the k-Wave toolbox acoustic simulations, from which ultimately the simulated ultrasound images are created.

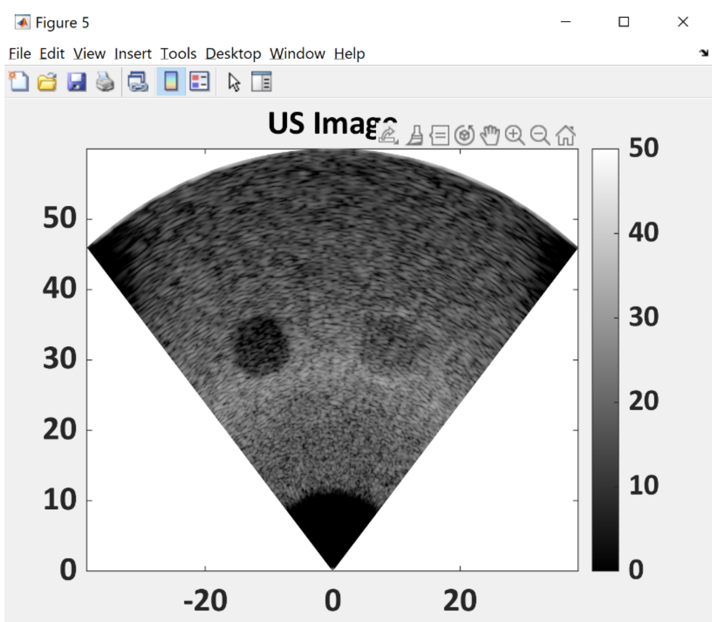

Fig. 4) Final Ultrasound image generated from the example phantom/density map shown above. The contrast levels in each tissue class match the contrast levels selected from the dictionary.

Additional Examples – Prostate phantom

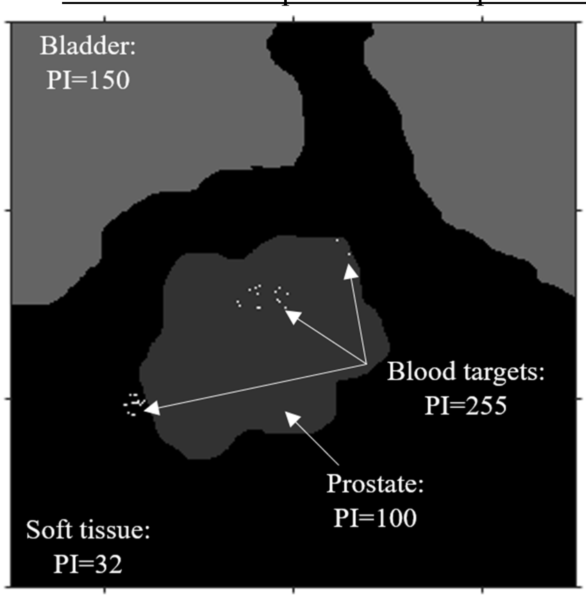

Fig. 5) Soft tissue: 1% heterogeneity. Prostate: 0.3% heterogeneity. Bladder: 0.05% heterogeneity. Blood Targets: 0.05% heterogeneity

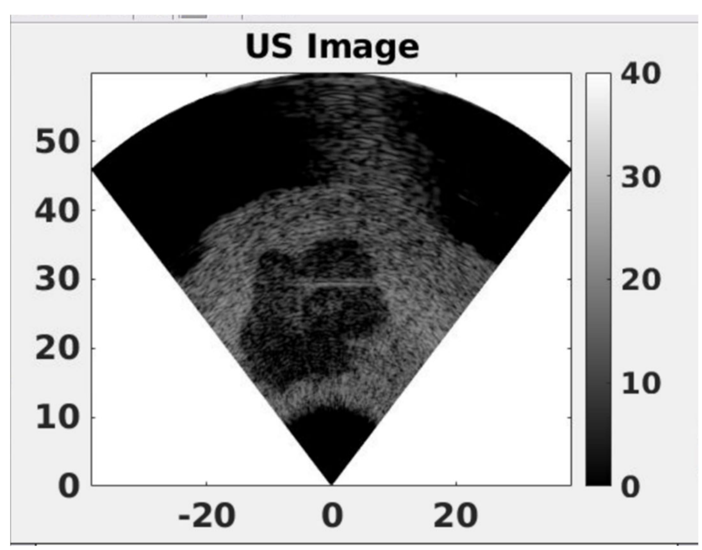

Fig. 6) Ultrasound image of prostate phantom

Additional Examples – Finger phantom

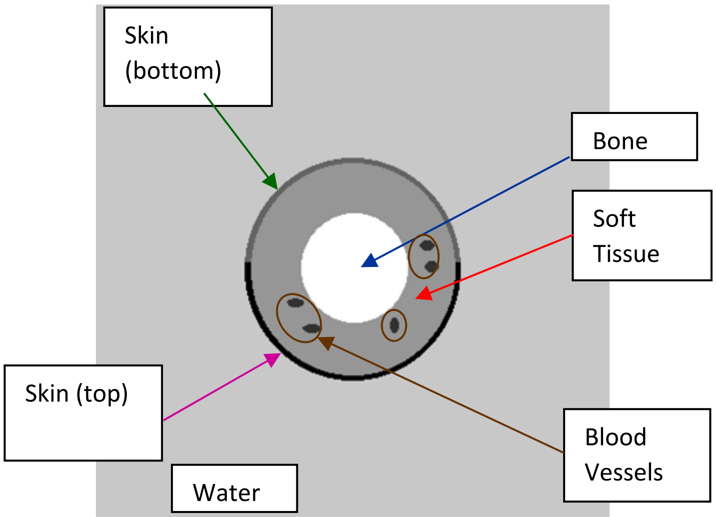

Fig 7.) Skin (top): pixel intensity 0, 1% heterogeneity. Blood Vessels: intensity 50, 0.05% heterogeneity. Skin (bottom): intensity 100, 0.1% heterogeneity. Soft Tissue: intensity 150, 0.6% heterogeneity. Bone: intensity 255, 0.1% heterogeneity. The phantom is flipped upside down due to the transducer location being at the bottom.

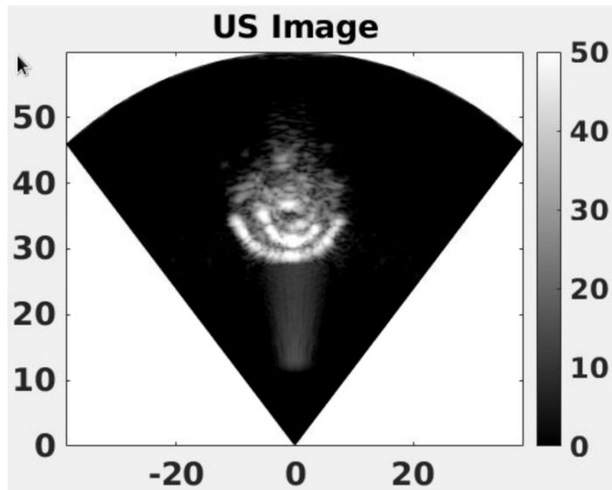

Fig. 8) US image for finger phantom