On Multifractal Tissue Characterization in Ultrasound Imaging

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Objectives

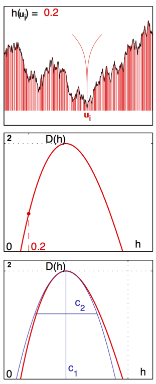
- **Investigate how multifractal properties of a simulated tissue correlate with the ones estimated from a simulated ultrasound image in RF, envelope and B-mode domains.**

Background and Motivations

- Biological experiments sustain multifractal tissue behavior [1]
- Existing studies show the interest of analyzing the fractal or multifractal behavior of human tissues from ultrasound images [2,3]

Multifractal analysis [4, 5]

Local regularity and multifractal spectrum

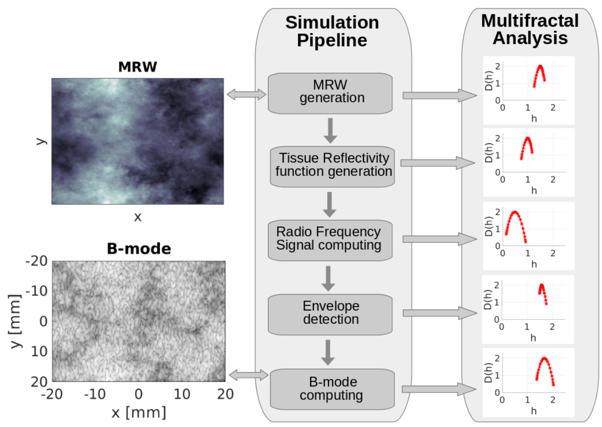


- Multifractal analysis enables texture in an image $F(x)$ to be characterized on the *fluctuations* of its *local regularity index* $h(x) > 0$, referred to as the Hölder exponent
  $h(x_0) \triangleq \sup_\alpha\{\alpha : |F(x) - F(x_0)| < C|x - x_0|^\alpha\}$
- *Multifractal spectrum* $\mathcal{D}(h)$ provides a global description of the geometric repartition of $h(x)$ in space and is defined as the Haussdorf dimension of the sets of points x with identical exponent $h(x) = h$
- In practice, it is often approximates by a parabola

$$\mathcal{D}(h) = 2 + (h - c_1)^2/(2c_2) \quad (1)$$

Ultrasound image simulation pipeline

- Generate a multifractal random walk (MRW) image with known multifractal spectrum following (1)
- Generate uniform randomly distributed scatterers with amplitudes drawn from a zero mean Gaussian distribution with variance prescribed by the value of the nearest MRW image pixel
- Generate RF, envelope and B-mode ultrasound images by convolution of the tissue reflectivity function (TRF) with a PSF

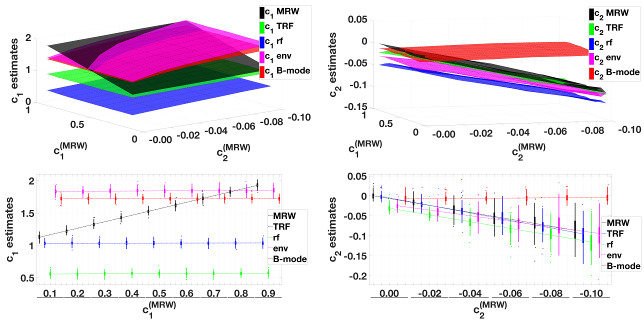


- Multifractal analysis is conducted at each level of the simulation pipeline

Results

1) Simulations:

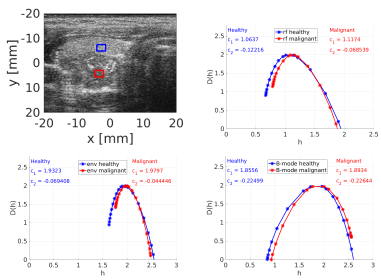
- MRW simulations for $c_1 \in (0.1, 0.2, \ldots, 0.9)$ and $c_2 \in (-0.1, -0.08, \ldots, -0.02, 0)$, 100 independent realizations for each (c_1, c_2) couple
- c_1 and c_2 were estimated from MRW, TRF, RF, envelope and B-mode images



- Estimates c_1 for any (TRF, RF, envelope and B-mode) simulated image are not coherent with the values prescribed for c_1
- Estimates c_2 for the simulated TRF, RF and envelope images strongly correlate with the values prescribed for c_2

2) *In vivo*:

- Multifractal spectra were estimated for two image patches extracted from tumor and healthy thyroid tissues



- Multifractal spectra estimated on RF and envelope images have different shapes for the healthy and pathological tissues reflected by different values $c_2 < 0$
- The positions of the multifractal spectra, quantified by c_1, coincide

Conclusions

- **Self-similarity properties, quantified by c_1, are shown not to be preserved by ultrasound images, while multifractal behavior, quantified by c_2, show a good correlation compared to simulated tissues**
- **The proposed simulation pipeline shows that B-mode images are not able to preserve tissue multifractal behavior**
- **Results are confirmed by one *in vivo* thyroid ultrasound image**

References

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