Statistical Models Towards Ultrasonic Characterization of Ovarian Tissues

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1. INTRODUCTION

ULTRASONIC PROPAGATION IN TISSUE

Sound is a longitudinal propagation of energy → mechanical motion of the medium particles through which it travels is provoked (waves theory)

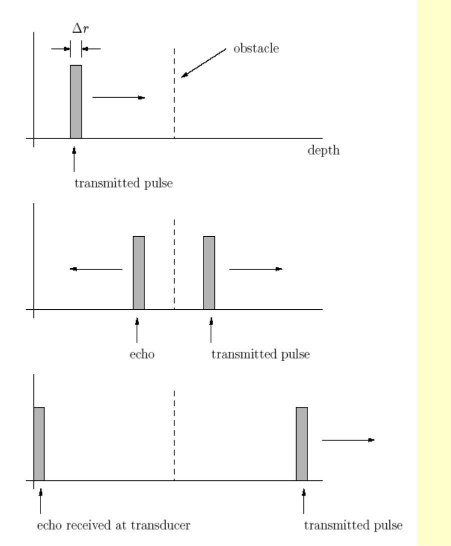

figure from [1]

During one time period, a short pulse is send out by the transducer; this pulse creates a pressure wave that travels along a 'beam' trajectory. During such travel, it can potentially meet a variety of physical phenomena and acoustical properties ("reflectors").

Whenever an ultrasound (US) pulse is send into the human body, it might propagate trough different tissue types and depending on the acoustical properties of these tissue types the pulse will interact differently. In between two successive pulses, the transducer receives echoes that are reflected ("backscattered echoes").

US imaging is based on transmission and backscattering of US pressure waves

STATISTICAL NATURE OF SPECKLE

A) Boundaries between homogeneous structures that are **larger** than the wavelength (λ) will lead to specular (strong) reflections

B) In an inhomogeneous medium, when the US beam meets structures that are **smaller** than the wavelength the reflection becomes omni-directional → scatter.

Scattering and reflections are the same physical thing; the two situations differ in the spatial distribution of the backscattering amplitudes.

Small scatterers that are **randomly** distributed in a resolution cell, produce echoes that interfere. The signal that is detected from a resolution cell is the result of the accumulation of these random scatterings

$$s(t) = \sum_{n=1}^{N} \alpha_n \cos(\phi_n)$$

α_n = amplitude of n-th scatterer
ϕ_n = Phase of the n-th scatterer

ENVELOPE DETECTION

The signals received in first line by the transducer have to be **transformed** into so called envelope data in order to create an **image**. This is done by a technique called 'quadrature demodulation'.

⇩

After the demodulation we have the original data (I) and an imaginary part (Q)

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Envelope then equals the amplitude $V = \sqrt{I^2 + Q^2}$

GRAYSCALE

For image **display**, this envelope is transformed into an integer number → every pixel of the image matrix contains a value between and 0 and 255 (0=black and 255=white)

2. OBJECTIVE

Potential usage of the statistics of the envelope of the backscattered signals in ovarian tissue characterization, with emphasize on discriminating healthy from cancerous tissue.

3. POSSIBLE MODELS FOR THE ENVELOPE SIGNAL

SCATTERING CONDITIONS

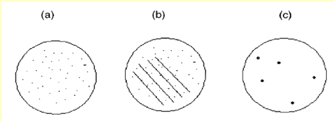


figure from [2]

a) Random alignment of a large number of scatterers (Rayleigh situation)

b) Randomly located scatterers together with regularly spaced scatterers (Post-Rayleigh situation)

c) Small number of scatterers (Pre-Rayleigh situation)

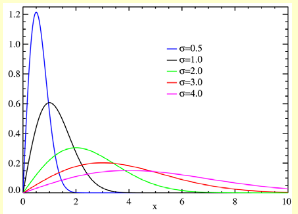
RAYLEIGH DISTRIBUTION

$I \sim N(0,\sigma)$

$Q \sim N(0,\sigma)$

The envelope will be Rayleigh distributed

$$f(x) = \frac{x \exp\left(\frac{-x^2}{2\sigma^2}\right)}{\sigma^2}$$



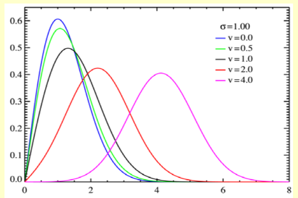
Conditions:

- **Large number** of scatterers (N)
- **Randomly located** scatterers ($\phi_n \sim U(0, 2\pi)$)
- Small scatterer spacing compared to wavelength

•Rayleigh is good for the ideal situation (see fig2.a)

RICIAN DISTRIBUTION

When additionally the tissue contains an alignment of periodically spaced scatterers (not random), a so-called coherent component (v) is added to the signal.



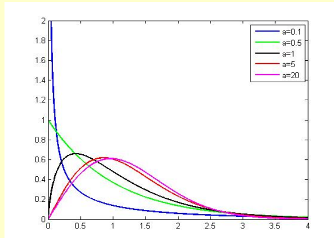
$$f(x) = \frac{x}{\sigma^2}\exp\left(\frac{-x^2+v^2}{2\sigma^2}\right) I_0\left(\frac{vx}{\sigma^2}\right)$$

(I_0 is the zero[th]-order modified Bessel function)

- The smaller the coherent component (v), the closer to Rayleigh
- Rician accounts for regularly spaced structures (see fig2.b)

K DISTRIBUTION

Scatterer density may not be large or scatterers may be correlated. For the situation of a small 'effective' number of scatterers the K distribution was derived.



$$f(x) = 2\left(\frac{x}{2}\right)^a \frac{b^{a+1}}{\Gamma(a)} K_{a-1}(bx)$$

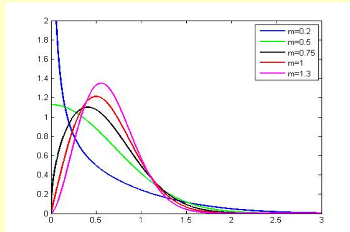
(K_w is the modified Bessel function of second kind and order w)

- The higher the value of a, the closer to Rayleigh
- K is applicable when N is low (see fig2.c)

NAKAGAMI DISTRIBUTION

Literature suggested the Nakagami distribution that is **general, accounts for all of the above situations** has not too many computational difficulties.

$$f(x) = \frac{2m^m}{\Gamma(m) o^m} x^{(2m-1)} \exp\left(-\frac{mx^2}{o}\right)$$

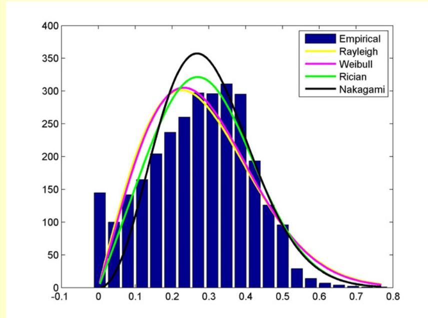


PARAMETERS AND THEIR INTEREST

Distribution	Parameters	Interpretation	Remarks
Rayleigh	σ	Scale	
Rician	σ	Scale	
	v	Strength of the coherent component	$v \approx 0$ → Rayleigh
K	a	Shape; Effective number of scatterers in the range cell	$a \approx \infty$ → Rayleigh
	b	Scale	
Nakagami	m	Shape; degree of heterogeneity in the range cell	0 < m < 1 → pre-Rayleigh m = 1 → Rayleigh m > 1 → post-rayleigh
	o	Scale	
Weibull	a	Shape	0 < a < 2 → pre-Rayleigh a = 2 → Rayleigh a > 2 → post-Rayleigh
	b	Scale	
	SNR	Signal-to-noise Ratio	For Rayleigh → SNR=1.91

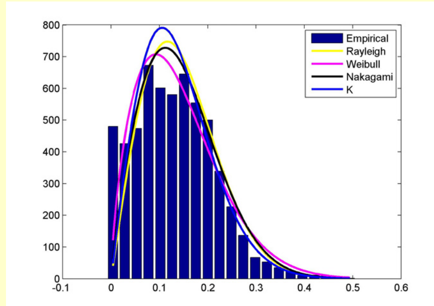
4. SOME RESULTS (On grayscales)

Patient id	Age	Pathology	Figo	Site of ovary
07_010_L	38	Ovarian Cancer	3B	Left



N	Distribution			Kolmogorov-Smirnoff Stat	Chi2 Stat
2925	*Rayleigh*	σ	0.2259	0.0951	504.7
	Weibull	a	2.0534	0.089	518.3
		b	0.3209		
	Rician	σ	0.1551	0.0491	487.85
		v	0.2323		
	K	a	Na	Na	Na
		b	Na		
	Nakagami	m	1.5661	0.0798	2978.1
		o	0.1054		
		SNR	2.0986		

Patient id	Age	Pathology	Figo	Site of ovary
07_069R_F2	56	Normal	.	Right



N	Distribution			Kolmogorov-Smirnoff Stat	Chi2 Stat
5850	*Rayleigh*	σ	0.1164	0.0634	721.8
	Weibull	a	1.6834	0.062	342.2
		b	0.1582		
	Rician	σ	Na	Na	Na
		v	Na		
	K	a	15.53	$> 10^{25}$	$>10^{25}$
		b	50.28		
	Nakagami	m	0.9302	0.0532	496.2
		o	0.0271		
		SNR	1.72		

5. REFERENCES

1. Dr Andrew Seagar and Dr David Liley. Basic Principles of Ultrasound Imaging System Design. 2002.
Ref Type: Report

2. Shankar, P. M., et al. "A General Statistical Model for Ultrasonic Backscattering from Tissues." IEEE Trans.Ultrason.Ferroelectr.Freq.Control 47.3 (2000): 727-36.

3. Vinayak Dutt. "Statistical Analysis Of Ultrasound Echo Envelope." Diss. 1995.