Instituto Tecnológico y de Estudios Superiores de Monterrey

Procesamiento de Imágenes Médicas para el Diagnóstico (Grupo 101)

Ultrasound Exercises

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Ultrasound Exercises

1. **Ultrasonic waves.**
   a. **What are reflection, refraction, scatter, and absorption? What is their effect on an ultrasound image?**

Reflection occurs when the wave passes between two tissues of different acoustic impedances and a fraction of the wave “bounces” back (Vajuhudeen, 2022). Refrcation occurs if it travels between tissues with different propagation speeds, causing that the incident pulse strikes an interface with a different propagation speed, due to its density or elasticity, which changes the direction of the wave (Murphy, 2021). Scatter effect occurs when a sound wave strikes a structure with a different acoustic impedance to the surrounding tissue and which is smaller than the wavelength of the incident sound wave (Rock, 2021). Absorption is the reduction in intensity of the sound waves as it passes trough tissue. Most of the energy lost is in the form of heat (Morgan, 2017).

   b. **What is the effect of the acoustic impedance on the reflection?**

The acoustic impedance difference between two media is directly propotional to the reflection and indirectly proportional to the tranmission of the sound wave (OpenStax, 2022).

   c. **What is the physical reason to avoid an air gap between the transducer and the patient? How can it be avoided?**

Air has a high acoustic impedance and, for that reason causes a high reflection of the image, not allowing the transmission of the sound wave. To minimize this effect is important to use an interface between the probe and the phantom; this interface must have the same acoustic impedance than the phantom.

   d. **What is constructive interference? How is this used to focus the ultrasoni beam? And how is it used to sweep the ultrasonic beam?**

Constructive interference occurs when two waves add together when both are in phase, so the amplitude of the resulting wave is equal to the sum of the individual ampltitude. This kind of signal processing and analysis is aplicated in phase scans that take a high resolution scan, and that can be modified by triggering the signal of the probes with a slight delay between every pulse, with the ability to create “curve” signals (SAOSU, s.f.).

2. **Calculate the reflection coefficient at air/tissue transitions.**

$$R = \frac{(z_1 - z_2)^2}{(z_1 + z_2)^2} = \frac{(1.6 - 0.0004)^2}{(1.6 + 0.0004)^2} = \frac{1.5996^2}{1.6004^2} = 0.9990005$$

3. **Which methods do you know are used to measure the velocity of blood?**

Doppler Ultrasound, Color Doppler, Continuos Wave Doppler.

4. **Given an ultrasoun scanner with the following characteristics**
   - **5 MHz phased array transducer**
   - **16-bit, 20 MHz AD converter**
   - **256 Mb image memory (RAM)**
   - **Operating mode: B-mode acquisition; 3000 transmitted ultrasonic pulses per secons; image depth 10 cm; number of scan lines 60; sector angle 60º**

   The ultrasound velocity is 1530 m/s.

   a) **What is the image frequency (frame rate)?**

$$FR = \frac{3000\ pps}{60\ nsl} = 50\ fps$$

   b) **How long does it take to fill the complete image memory with data?**

$$t = \frac{(256Mb)\ (2^{20})}{20x10^6} = 13.42\ s$$

   c) **How many images can maximally be stored in memory?**

$$I = FRt = (50\ fps)(13.42\ s) = 671\ images$$

5. **In Continuous Wave (CW) Doppler the signal is subdivided into time segments. Explain the consequence of shorter time segments on the velocity resolution and on the temporal resolution.**

If the Continuous Wave Doppler uses shorter time segments, it will have a better resolution in both, velocity and temporal measurements, due to the capacity to calculate the change in a smaller gap that reduces the error in the calculations.

6. **Doppler imaging. Given**
   - **Velocity of blood: 0.3 m/s**
   - **Trasmitted pulse frequency: 5 MHz**
   - **Pulse repetition period: 0.1 ms**
   - **Velocity of ultrasound: 1500 m/s**

   a) **What is the maximal depth that can be measured with the given pulse repetition period?**

$$\Delta x = \frac{V_{US}T}{2} = \frac{\left(1500\ \frac{m}{s}\right)(0.0001\ s)}{2} = 0.075\ m = 75mm$$

   b) **What would be the maximal pulse repetition period to avoid aliasing?**

$$\Delta f = \frac{V_B f}{2V_{US}} = \frac{\left(0.3\frac{m}{s}\right)(5x10^6Hz)}{2\left(1500\frac{m}{s}\right)} = 500\ Hz$$

c) **Calculate the measured phase shift (in degrees) between subsequent pulses reflected by blood.**

$$f_d = \frac{2\ v\ cos\theta}{\lambda} = \frac{2\ v\ cos\theta}{\frac{v_{luz}}{f}} = \frac{2\left(0.3\frac{m}{s}\right)}{\frac{300{,}000{,}000\frac{m}{s}}{\frac{1}{0.1\ ms}}} = 0.0002\ Hz$$

$$Phase\ Shift = \left(\frac{0.0002\ Hz}{1}\right)\left(\frac{360º}{1\ Hz}\right) = 0.072º$$

7. **Using PW Doppler, samples $s_j, j = 1, 2, \dots$ are taken of the following signal of a blood vessel**

$$\boldsymbol{s_j = 18sin\left(\frac{2}{5}\pi j + 0.35\right)mV}$$

The pulse repetition frequency is 12 kHz. The frequency of the transmitted pulse is 2.5 MHz. The velocity of the ultrasonic signal in soft tissue is 1530 m/s.

a) What is the velocity of blood (in the direction of the transducer)?

$$f(i) = \frac{1}{5};\ \ T = 5\ samples;\ \ f_s = 12kHz \to T = \frac{5}{12000} \to\ \Delta f = \frac{12000}{5} = 2400$$

$$v_{max} = \frac{cf}{2PRF} = \frac{(5\ samples)\left(1530\frac{m}{s}\right)}{2(12kHz)} = 0.31875\frac{m}{s}$$

b) What is the maximal velocity v_{max}that can be measured without artifacts?

$$v_{max} = \frac{fc}{2PRF} = \frac{(6kHz)\left(1530\frac{m}{s}\right)}{2(12kHz)} = 382.5\frac{m}{s}$$

c) **What is the maximal distance from the transducer required to measure this maximal velocity v_{max} without artifacts?**

$$z = \frac{c^2}{8\ f\ v_{max}\ cos\ \theta} = \frac{\left(1530\frac{m}{s}\right)^2}{8\ (12kHz)\left(382.5\frac{m}{s}\right)} = 0.06375\ m$$

$$z = \frac{c}{2PRF} = \frac{1530\frac{m}{s}}{2\ (12kHz)} = 0.06375\ m$$

d) What is the measured velocity of blood if its real velocity equals v_{max} + 1 m/s?

The measured velocity will be 1 m/s, because the transducer is going to capture just the difference between the velocity of blood and the maximal velocity it can capture, which gives us $v_{max} + 1\frac{m}{s} - v_{max} = 1\frac{m}{s}$

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