DIGITAL IMAGE PROCESSING IN ULTRASOUND IMAGES

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***ABSTRACT*-- Image processing plays a vital role in the development of medical industry especially ultrasound medical images. Image acquisition is carried out using ultrasound equipments like transducer, scanner, and CPU and display device. There are mainly four modes of ultrasound imaging A-mode, M-mode, B-mode and Doppler-mode. Ultrasound imaging plays crucial role in medical imaging due to its non-invasive nature, low cost and capability of forming real time imaging. Modern ultrasound systems are signal processing intensive. Advanced techniques of signal processing are used to provide better image quality and higher diagnostic value.**

Keywords: **Ultrasound, Medical Imaging, Digital Image Processing.**

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I. INTRODUCTION

Ultrasonography is a diagnostic imaging technique that is used for visualizing human body structures including tendons, muscles, joints, vessels and internal organs. It is based on ultrasound.

Ultrasound is a cyclic sound pressure wave with a frequency greater than the upper limit of the human hearing range. Ultrasound is thus not separated from "normal" (audible) sound based on differences in physical properties, only the fact that humans cannot hear it. Ultrasound devices operate with frequencies from 20 kHz up to several gigahertz. Ultrasonic is the application of ultrasound. Ultrasound can be used for imaging, detection, measurement, and cleaning.

Sonography or Ultrasonography is widely used in medical. Sonographers typically use a hand-held probe (called a transducer) that is placed directly on and moved over the patient. [1]

The images that are generated using Ultrasound imaging is commonly known as Ultrasound Scanning - is called an *Ultra sonogram*. The resolution of the image will be better by using higher frequencies but this at the same time limits the depth of the penetration.

II. IMAGE ACQUISITION

A. Ultrasound Equipments

Ultrasound equipment basically consists of a transducer, scanner, computer and monitor.

The transducer, also called an ultrasound probe, emits pulses of sound waves between 3.5 to 7.0 megahertz, explains Obstetric Ultrasound. Transducers come in different shapes and sizes, including a flat-surface type called a linear array transducer and a convex array transducer, which fits better for pregnant women.

The CPU is the brain of the ultrasound machine. The CPU is basically a computer that contains the microprocessor, memory, amplifiers and power supplies for the microprocessor and transducer probe. The CPU sends electrical currents to the transducer probe to emit sound waves, and also receives the electrical pulses from the probes that were created from the returning echoes. The CPU does all of the calculations involved in processing the data. Once the raw data are processed, the CPU forms the image on the monitor. The CPU can also store the processed data and/or image on disk.

The scanner is often part of the transducer and operates to collect the reflection of the sound waves that return after bouncing off the internal systems. The ultrasound equipment may also be connected to a printer, video recorder or data storage device that can make a copy of the scan for later reference. [2]

B. Generating Ultrasound Images

Medical Ultrasound imaging is done using ultrasonic waves in 3 to 20 MHz range. Ultrasound waves are produced from the transducer and travel through body tissues and when the wave reaches an object or surface with different texture or acoustic nature, it is reflected back. These echoes are received by the apparatus i.e. the transducer array and changed into electric current. These signals are amplified and conditioned and shown on a display device in real time. [3]

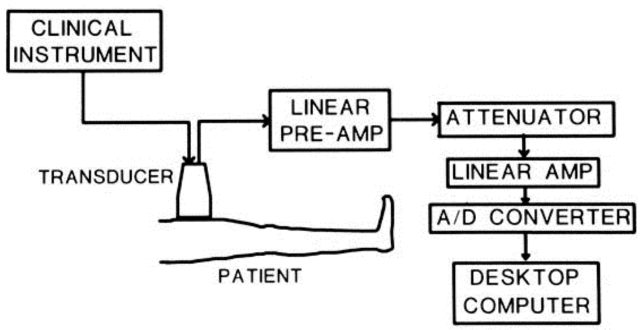

Figure. Ultrasound System For Image Acquisition and Analysis

After collection, the computer analyzes the data and presents it in visual form on the monitor. Image acquisition is based on the principle that when a sound wave strikes an object, it bounces back, or echoes. By measuring these echo waves, it is possible to determine the objects' size, shape and nature.

The image is created based on the amplitude (loudness), frequency (pitch) and time it takes for the ultrasound signal to return from the area of the patient being examined to the transducer, as well as the composition of body tissue through which and the type of body structure the sound travels through. Data are shown as 2D vector of pixels (picture elements) whose intensity is represented on a grey-scale: position and grey value correspond to echo source and amplitude.

C. *Time Gain Compensation (TGC)*

They calculate the time interval between sending the signal and receiving the echo to determine the distance to an object. When passing through the human body, a portion of the ultrasound waves get absorbed by the body cells.

This absorption will get accumulated and the waves travelling deeper will become weaker and weaker. This signal attenuation is compensated by applying a distance (time) varying gain value to the reflected signal. This process is called TGC.As the ultrasound beam travels deeper in tissue, its intensity is progressively attenuated by tissue absorption of sound energy and by scattering of the beam in different directions by tissue interaction. To compensate for this loss of sound energy, the returning echoes are progressively amplified proportional to the time of their return to the transducer. Echoes from deeper in the tissue return later to the transducer and are amplified to a greater degree. This method of amplification is called time-gain-compensation.

III. INTERACTION OF ULTRASOUND WITH MATTER

- Characteristics of waves
- Physical properties of tissues through which beam passes.

Acoustic impedence-

- The extent to which the medium particles will resist change due to mechanical disturbance is known as acoustic impedence.
- Z(acoustic impedence)= density X velocity

Resistance increases in proportion to the density of medium and the velocity of ultrasound in the medium.

Acoustic boundaries-

- Position within tissue where value of acoustic impedence change.

Beam divergence and interference-

- Divergence refers to spreading of beam energy as it moves away from source. Divergence effects the intensity of beam both laterally(perpendicular to beam direction) and axially(along beam direction).
- Interference refers to manner in which different parts of the wave interact with each other. It can lead to either strengthening or weakening of the wave.

A. *Acoustic Impedance*

As ultrasound waves travel through tissues, they are partly transmitted to deeper structures, partly reflected back to the transducer as echoes, partly scattered, and partly transformed to heat.

For imaging purposes, we are mostly interested in the echoes reflected back to the transducer. The amount of echo returned after hitting a tissue interface is determined by a tissue property called acoustic impedance.

Air-containing organs (such as the lung) have the lowest acoustic impedance, while dense organs such as bone have very high-acoustic impedance. The intensity of a reflected echo is proportional to the difference (or mismatch) in acoustic impedances between two mediums. If two tissues have identical acoustic impedance, no echo is generated. Interfaces between soft tissues of similar acoustic impedances usually generate low-intensity echoes. Interfaces between soft tissue and bone or the lung generate very strong echoes due to a large acoustic impedance gradient.

Attenuation of ultrasound in tissues-

- Diminishing the intensity of ultrasound beam as it passes through the tissues are said to attenuate the beam.
- Absorption refers to conversion of ultrasound energy to thermal energy whereas attenuation refers to total propagation losses that result in reduction of beam intensity. These losses include-
  Reflection
  Scattering
  Refraction
  Absorption

(a) Reflection:- When an incident ultrasound pulse encounters a large, smooth interface of two body tissues with different acoustic impedances, the sound energy is reflected back to the transducer. This type of reflection is called specular reflection.

- Occurs- 1. depending on the size of the boundary relative to beam.
  2. Irregularities of shape on the surface of reflector.

- 2 types of reflections-

Specular –a specular reflector is an interface whose diameter is larger than one wavelength of ultrasound beam.

Non- specular reflections (scattering of ultrasound)

- Occurs when interface is smaller than beam.
- Scattering shows strong frequency dependence, increasing rapidly as the frequency of ultrasound is increased.

(b) Refraction:- Refraction refers to a change in the direction of sound transmission after hitting an interface of two tissues with different speeds of sound transmission. It is caused by a change of wavelength as the ultrasound crosses from the first medium to second while beam frequency remains unchanged.

In this instance, because the sound frequency is constant, the wavelength has to change to accommodate the difference in the speed of sound transmission in the two tissues. This results in a redirection of the sound pulse as it passes through the interface. Refraction is one of the important causes of incorrect localization of a structure on an ultrasound image. Because the speed of sound is low in fat and high in soft tissues, refraction artifacts are most prominent at fat/soft tissue interfaces.

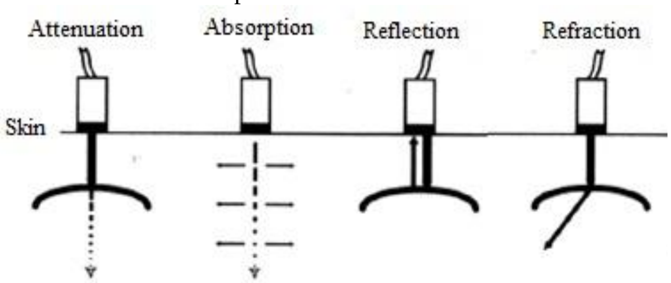

Figure. Wave Transmission

(c) Absorption:- Not all of the transmitted ultrasonic energy is reflected. In fact, most of the transmitted energy is absorbed by the tissue. Absorption refers to the dissipation (conversion) of acoustic energy into heat. [4]

Absorption is frequency dependent: The higher the frequency, the greater the absorption.

Although resolution is better at the higher frequencies, the penetration of the ultrasound signal is not as good as the lower frequencies.

Absorption is the process by which energy in the ultrasound beam is transferred to propagating medium, where its transformed to different form of energy mostly heat.

- Extent of absorption is effected by-

1. Viscosity- measure of frictional forces between particles of medium as they move past one another.
2. Relaxation time- measure of time taken by medium particles to revert back to their original mean positions. Longer the relaxations time of medium the higher the absorption of ultrasound.
3. Frequency- absorption of ultrasound increases with increasing beam frequency.

Effect of beam frequency is that :

- Absorption is directly proportional to frequency.
- Attenuation of ultrasound increases.
- Also probability of beam scattering increases

IV. MODES

There are different modes of ultrasound imaging.

The most common modes are

(a) A-mode

(b) M-mode - to assess moving body parts (e.g. cardiac movements) from the echoed sound.

(c) B-mode – the basic two-dimensional intensity mode

(d) Doppler-mode - pseudo coloring based on the detected cell motion using Doppler analysis.

A. A-Mode

A-mode (amplitude mode) is the oldest, simplest type mode and it measure the reflectivity at different depth below the transducer position. A single transducer scans a line through the body with the echoes plotted on screen as a function of depth. Attenuation due to high freq is not a problem as the desired imaging depth is small.

B. M-Mode

In M-mode (motion mode) ultrasound, pulses are emitted in quick succession – each time, either an A-mode or B-mode image is taken. This approach is used for the analysis of moving organs. Over time, this is analogous to recording a video in ultrasound. As the organ boundaries that produce reflections move relative to the probe, this can be used to determine the velocity of specific organ structures.

C. B-Mode

B-mode (Brightness mode) involves transmitting small pulses of ultrasound echo from a transducer into the body. In this case the A-mode information is shown as pixel intensity on a monitor. As the ultrasound waves penetrate body tissues of different acoustic impedances along the path of transmission, some are reflected back to the transducer (echo signals) and some continue to penetrate deeper. The echo signals returned are processed and combined to generate an image. Thus, an ultrasound transducer works both as a speaker (generating sound waves) and a microphone (receiving sound waves). The ultrasound pulse is in fact quite short, but since it traverses in a straight path, it is often referred to as an ultrasound beam.

Usually only a small fraction of the ultrasound pulse returns as a reflected echo after reaching a body tissue interface, while the remainder of the pulse continues along the beam line to greater tissue depths.

B-mode can be used to study both stationary and moving structures but high frame rate is needed to study motion. [5]

D. Doppler-Mode

A Doppler ultrasound study may be part of an ultrasound examination. Doppler ultrasound is a special ultrasound technique that evaluates blood flow through a blood vessel,

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including the body's major arteries and veins in the abdomen, arms, legs and neck. Doppler ultrasound measures the direction and speed of blood cells as they move through vessels. The movement of blood cells causes a change in pitch of the reflected sound waves (called the Doppler effect). A computer collects and processes the sounds and creates graphs or color pictures that represent the flow of blood through the blood vessels.

Doppler Effect: change in frequency of sound due to the relative motion of the source and receiver.

There are three types of Doppler ultrasound:

- Color Doppler uses a computer to convert Doppler measurements into an array of colors to visualize the speed and direction of blood flow through a blood vessel.
- Power Doppler is a newer technique that is more sensitive than color Doppler and capable of providing greater detail of blood flow, especially when blood flow is little or minimal. Power Doppler, however, does not help the radiologist determine the direction of blood flow, which may be important in some situations.
- Spectral Doppler: Instead of displaying Doppler measurements visually, Spectral Doppler displays blood flow measurements graphically, in terms of the distance traveled per unit of time.

V. ULTRASOUND BEAM SHAPE

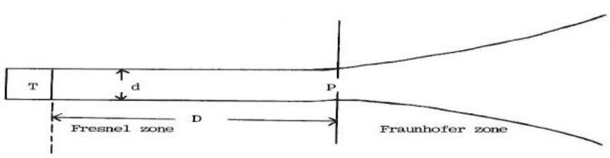
It is used to describe the manner in which spatial resolution of a beam changes with distance from the source.

T=transducer

d=beam width

P=plane and

D=fresnel zone or near field



Factor Influencing beam shape:-

Effect of Source size

Effect of beam frequency

Effect of beam focusing

(a) Effect of Source size

- Small source provide narrow beam so shorter fresnel zone and beam diverges rapidly beyond the near field.
- Provide poor quality image
- Large source provide wider beam so large fresnel zone and beam diverges gradually.
- provide good quality image

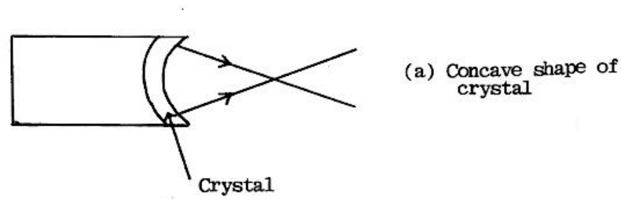
(b) Effect of beam frequency

- With the increase in beam frequency fresnel zone increases.
- Angle of divergence diminish with increase in frequency.

(c) Effect of beam focusing

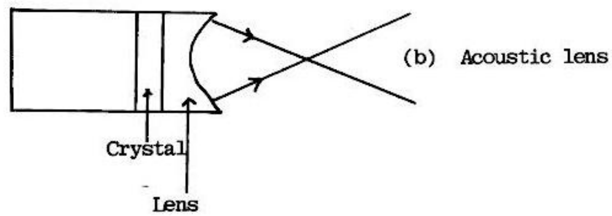
Shape of crystal element:-

- Crystal element shaped by concave curvature and degree of focusing depend on the extent of curvature(radius of curvature)
- It is internal focusing because it is effected in the crystal itself.

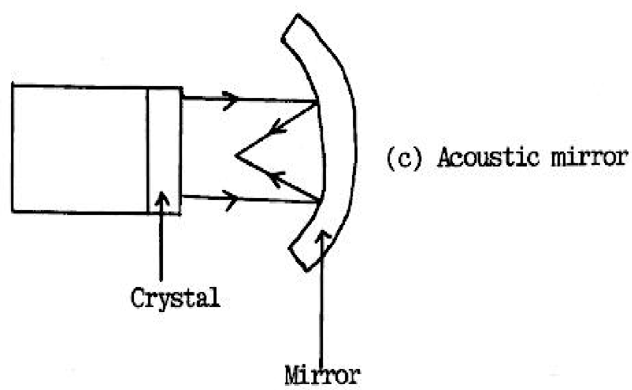


Acoustic Lenses

- Acoustic lenses made from material which propagate ultrasound at different velocities.
- It is external focusing



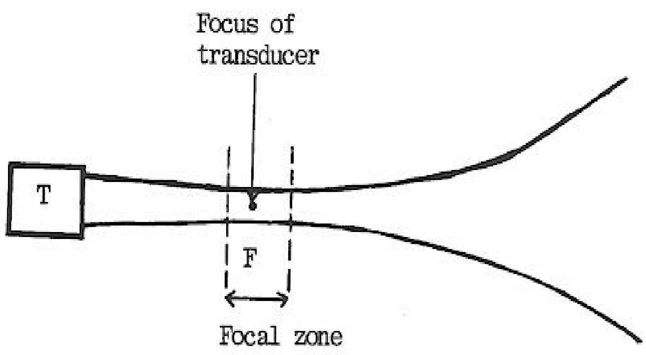
Acoustic Mirrors:- A concave mirror is used to focus ultrasound by reflection



Electronic Focusing

- It is employed in multi-crystal transducer.
- Provide variable/dynamic focusing.

Focus of a transducer:- focus is a point which is equidistant in the time from all the points on the surface of the transducer.



Optimization of spatial resolution and tissue depth

- Narrow beam will provide better spatial resolution and facilitate adequate tissue depth. This is achieved on the basis of:
- Size and shape of sound.
- Beam frequency
- Transducer focusing

VI. DIGITAL IMAGE PROCESSING IN ULTRASOUND IMAGES

Ultrasound images can contain more noise content – especially speckle noise. Noise is introduced at all stages of Image acquisition.

There could be noises due to

- The loss of proper contact or air gap between the Transducer and body
- The noise can be introduced during the beam forming process and also during the signal processing stage
- Even during the Scan conversion, there could be loss of information due to the interpolation.

Techniques for ultrasound image filtering and analysis focus a noise called speckles. Speckle is a particular type of noise which affects the medical ultrasound images. The speckle noise degrades the fine details and edge definition and limits the contrast resolution by making it difficult to detect small and low contrast lesions in body.

Different axial and lateral filters are applied on the signals at different stage to improve the image quality. The processed signal will then be given to the Scan conversion module as scan lines, which will actually generate the image from the scan lines by doing a geometric mapping.

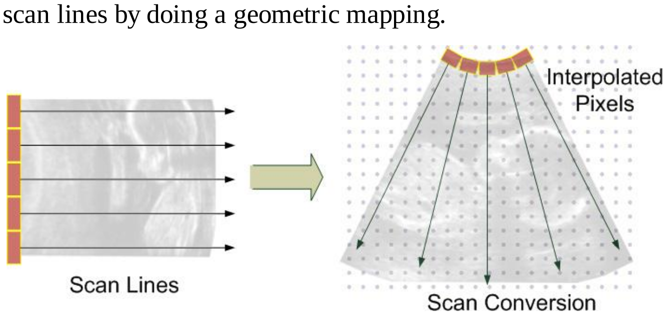


Figure. Scan Conversion

Different Digital Image Processing techniques are available for enhancing the quality and information content in the Ultrasound image.

Echo signals corresponding to individual beam-formed lines are processed using a very wide variety of techniques, for a wide range of objectives. All ultrasound scanners amplify the echo signals and compensate for attenuation losses.

Low noise pre-amplifiers are necessary to maximize penetration at a given operating frequency. Noise reduction and other benefits are achieved by using filtering that is linked to the centre frequency and bandwidth of the transmitted pulse.

The Noise reduction techniques in Ultrasound images can be broadly divided to two –

During acquisition and

After acquisition.

The former refers special processing modules added to the image acquisition system to suppress the noise and also to enhance the information content in the generated image.

The latter addresses Digital image processing techniques used to reduce the noise and thus enhance the quality of the acquired Ultrasound images.

The speckle noise can be reduced by wavelet-transformation, multi-look processing, spatial filtering or homomorphic filtering etc.. The multi-look processing is usually done during image acquisition. Speckle reduction by spatial and homomorphic filtering is performed on image after its acquisition. [6]

Ultrasound image quality can also be improved during the acquisition by

- Using high quality transducers
- Using gel to ensure proper contact and to avoid air gaps between body and transducer
- Using appropriate axial and lateral filters while doing the signal processing
- Using adaptive interpolation techniques while doing the scan conversion.

VII. ADVANTAGES

While the most common use of ultrasound equipment is visualizing the fetus in a pregnancy, there are other medical applications as well.

- Ultrasound can be used to examine the heart, thyroid gland and blood flow in veins and arteries. In cancer patients, ultrasound may be used to diagnose the disease or to guide biopsies or other procedures.
- Most ultrasound scanning is noninvasive (no needles or injections).
- It shows the structure of organs.
- Occasionally, an ultrasound exam may be temporarily uncomfortable, but it is almost never painful.
- Ultrasound is considered safe; instrument is less expensive and imaging is fast.
- Ultrasound examinations are painless and easily tolerated by most patients.
- Ultrasound is widely available, easy-to-use and less expensive than other imaging methods.

- Ultrasound imaging is extremely safe and does not use any ionizing radiation.
- Ultrasound scanning gives a clear picture of soft tissues that do not show up well on x-ray images.
- Ultrasound is the preferred imaging modality for the diagnosis and monitoring of pregnant women and their unborn babies.
- Spatial resolution is better in high frequency ultrasound transducers than it is in most other imaging modalities.
- Ultrasound provides real-time imaging, making it a good tool for guiding minimally invasive procedures such as needle biopsies and needle aspiration.

VIII. DISADVANTAGES

Following are some weaknesses of Ultrasonography images:-

- Ultrasound waves are disrupted by air or gas; therefore ultrasound is not an ideal imaging technique for air-filled bowel or organs.
- Images are of low resolution.
- The presence of noise components is more on Ultrasound image compared to other costlier methods like CT and MRI.
- Large patients are more difficult to image by ultrasound because greater amounts of tissue attenuates (weakens) the sound waves as they pass deeper into the body.

Ultrasound has difficulty penetrating bone and, therefore, can only see the outer surface of bony structures and not what lies within (except in infants who have more cartilage in their skeletons than older children or adults). For visualizing internal structure of bones or certain joints, other imaging modalities such as MRI are typically used. [7]

IX. CONCLUSION

In this paper we briefly reviewed how ultrasound images are generated, interaction of beam with matter, their modes of operating, beam shape, digital processing involved in ultrasonography and their advantages and disadvantages.

Medical ultrasonography is one of the popular techniques for imaging diagnosis and is preferred over other medical imaging modalities because it is noninvasive, portable and does not provide any harmful radiations. The disadvantage of ultrasonography is the poor quality of images, which is due to the presence of multiplicative speckle noise.

We can use wavelet transform to despeckling medical ultrasound. The wavelet transform is well adapted to point singularities, so it has a problem with orientation selectivity. This is a major drawback for wavelet-based image denoising technique.

Speckle noise affects all coherent imaging systems including medical ultrasound. In medical images, noise suppression is a particularly delicate and difficult task. A tradeoff between noise reduction and the preservation of actual image features has to be made in a way that enhances the diagnostically relevant image content. Removing speckle noise by retaining the important feature of the images is the real challenge to current system development.

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