Physics modern day medical field, and without it,

Government, Military

Physics is avery important aspect of the modern day medical field, and without it, thediagnosis of medical problems would be challenging to say the least. Inparticular, the world of medical imaging has benefited enormously from physics-baseddiagnostic techniques, such as Ultrasound. Ultrasound (or Ultrasonic) isdefined as a mechanical, longitudinal sound wave with a frequency exceeding theupper limit of human hearing.

However, despite the term referring to any soundwave with a frequency greater than 20kHz, ultrasound generally becomes usefulat much greater frequencies, in the range of 1-50MHz. Higher frequencies tendto be used for scanning areas close to the surface of the body as high frequencywaves are easily absorbed, whereas, lower frequencies waves are used to scan areasdeeper down in the body because they are more penetrating. In this highfrequency range, the sound waves can be used to scan over the human body via atransducer (as shown in Figure 1), and an internal image can be formed using the “ echoes” from internal organs1.

Figure 1.

Diagram of a Transducer2. Transducers: Ultrasoundis produced and subsequently detected by the ultrasound transducer, illustratedin Figure 1. Transducers can send andreceive high frequency signals and later convert them into electrical signalsthat can be diagnosed. A transduceris a device used to convert some other form of energy into an ultrasonicvibration. There are numerous types of transducer, each characterised by theenergy source and the medium into which the waves are being produced. There areforms of mechanical devices, including gas-driven or pneumatic transducers, however, electromechanical transducers are far more useful.

The two most commonforms of electromechanical transducer are the piezoelectric andmagnetostrictive devices. The magnetostrictive transducer uses a magnetic materialin which an applied oscillating magnetic field forces the atoms of the materialtowards and then away from each other, consequently producing a periodicvariation in length of the material, which causes a high-frequency vibration. Thisform of transducer is mainly used in the lesser frequency ranges and aretypically found in ultrasonic machining and ultrasonic cleaners. But, themost widely used and versatile type transducer is the piezoelectric crystaltransducer. This produces a mechanical vibration by converting an oscillatingelectric field that has been applied to the crystals (can be quartz, Rochellesalt and certain types of ceramic). Piezoelectric transducers are so popular asthey can be operated at all output levels over the whole frequency range. Different shapes are chosen for certain applications, for example, a concavedshape provides a focused ultrasonic wave, whilst a disc shape will create aplane ultrasonic wave 3. The process of Ultrasound Imaging: A voltage israpidly applied and removed across the transducer repeatedly so ultrasoundwaves can be produced by the piezoelectric crystals expanding and relaxing.

Thetransducer is applied to the skin with a gel and it directs ultrasound wavesinto the internal anatomy. As the ultrasound waves encounter tissues withdifferent characteristics and densities, they produce ‘ echoes’ that reflectback to the transducer. This occurs more than 1000 times per second. Echoeswon’t be produced if there’s no difference in tissue or between tissues, e. g. blood and bile. When the reflected waves reach the transducer, thepiezoelectric crystals compress and relax, consequently generating a voltagethat corresponds to the intensity of the ultrasound wave that hits them. Theinformation gathered by the crystals is then processed by a computer to displayan image on a screen (sonogram).

The crystals are repeatedly activated manytimes in such a way that a complete image frame is formed around 20 times persecond, so that real-time motion is displayed in the ultrasound image. Any time theultrasound waves reaches an interface (change in medium), such as an organ inthe body, part of the wave will be reflected, and the rest will be transmittedthrough the medium. The respective intensities of the reflected and transmittedwaves will clearly be less than that of the original wave, and this couldbecome an issue when detecting reflected waves from deep in the body tissue dueto their very low intensity. The ratio of the intensity of the reflected beamto the intensity of the incident beam is given by a relationship of theacoustic impedance, z, of the two materials either side of the interface (Figure 2). , where .

Figure 2. Equationrelating the ratio of the intensity of the reflected wave to the intensity ofthe incident wave4. Thedifference in density, and therefore impedance between tissues in the body isquite small, and so there isn't an immediate problem inside the body. However, there is a very large difference in acoustic impedance between air and thebody, and therefore an Aquasonic gel with a density like that of body tissue isused when applying the transducer for ultrasound imaging. It must also berecognised that the further the sound ' pulse' travels, the more likely it is tobe attenuated, so, to compensate, the signals from deeper tissues are amplifiedto give similar

intensities to waves from other boundaries. This creates aclearer signal and therefore, a better image. Figure 3. An ultrasound imageobtained of the heart’s left ventricle 5.

There arenumerous other uses for ultrasound outside of the medical field, one of themost notable is for marine ranging and navigating 6. Ultrasound in NavigationSonar (soundnavigation and ranging) has extensive marine applications. By emittingultrasonic sound pulses and recording the time it takes for the pulses toreflect off a distant object, the location of the object can be determined andits motion can be tracked. Ultrasonic waves are used as opposed to sound wavesbecause higher frequency sound waves travel much greater distances with lessdiffraction underwater 7. There aretwo forms of Sonar, active and passive.

Passive sonar is primarily used todetect noise from other marine objects (such as submarines, ships or marineanimals). Passive sonar is particularly useful for military vessels that wantto stay undetected as it does not involve emitting a signal. However, passivesonar is unable to measure the range of an object unless it’s usedsimultaneously with other passive devices. For example, two passive bodies atknown locations can also use triangulation to locate and track a third boat orsubmarine. Active sonar on the other hand, uses transducers to emit a signal orpulse of sound into the water. If there is an object in the path of the soundwave, the wave will ‘ bounce’ off the object and return as a signal to the sonartransducer.

The transducer, if equipped appropriately, can subsequentlydetermine the orientation and range of the object, by measuring the timebetween the emission of the sound pulse and the detection of the ‘ echo’ signal 8. It is worthnoting, as the ultrasonic wave reflects off a moving object, the frequency ofthe reflected wave will either increase or decrease depending on whether theobject is moving towards or away from the signal (the Doppler effect). Theamount of frequency shift can be used to determine the speed of a movingsubmarine for example, a very useful tool in marine military vessels. There aresome limitations with these techniques. For example, the distance over whichthese techniques can be used is restricted by temperature gradients in thewater, which cause the sound beam to bend away from the surface and create’shadow regions’ 9.

Ultrasoundis also used in ranging, to map the bottom of the ocean, producing charts ofdepth that are used for navigation, specifically in shallow waters. In themodern day, even small boats are equipped with sonic ranging devices that mapthe depth of the water so the navigator can keep the boat away from shallowpoints to avoid beaching 10. SummaryOverall, inthe medical field, ultrasound is a very effective technique for imaging anddiagnosis. It is a process that can be performed in real-time, and there is nodelay between the clinical picture and imaging. Also, there are no real healthrisks associated with ultrasound imaging, whereas x-ray imaging can be a healthrisk overtime due to exposure to radiation. However, there are limitations toultrasound, for example, ultrasound is not ideal for imaging an air-filledbowel or organs the bowel is obscuring.

This is because gas interferes withultrasound waves 11. Sonar isalso a useful technique in the modern day and can massively aid military andscientific vessels when navigating underwater. The downsides of sonar arecomparable to that of ultrasound imaging. The ultrasonic waves can be easilydisrupted by any external sound waves, including surface noises, other shipsand sea life. Unfortunately, most of these problems are unavoidable and limitultrasound as an imaging technique in the long run 12.