Introduction

Ultrasound is a growing area of research with applications expanding into various industries, having uses in supplying energy or penetrating a medium to measure reflective signatures. In medical diagnosis and monitoring, the latter use is more prevalent and inexpensive in comparison to other imaging methods such as MRIs and CT scans. This paper presents a technical review of ultrasound imaging applications in medicine, discussing commercially available products, underlying technology including techniques and characteristics, and requirements for their implementation.

Commercial Applications

Ultrasound imaging has uses in various facets of medicine including the imaging of organs and fetal development during pregnancy through sonography. Focused ultrasound is also used for cancer treatment among other diseases. A variety of products using ultrasound technology are available from manufacturers, however their pricing depends on specific applications. Ultrasound devices used for imaging in medical diagnosis are expensive due to health and safety concerns, and can range from $32,000 to $150,000 depending on size, portability, and features included [1]. The smaller portable devices such as GE’s Vivid i ($32,000) tend towards the lower pricing range, but have lower imaging resolution, and exclude features such as 4D imaging, unlike GE’s Voluson E8 BT08 ($135,000) or Phillip’ IU22 ($100,000) which include these features.

There is a continuous effort to make these devices smaller, more portable, and cheaper through means of using different applications of ultrasound and improving on the algorithms implemented to produce images. Research is on going in using higher frequency focused ultrasound (20 MHz and above) to image soft tissue more rapidly while still maintaining the ability to obtain a high-resolution image [2]. Other research topics include improving the material applied to the human body to reduce the loss factor involved in signal propagation through human tissue.

Underlying Technology

Ultrasound refers to frequencies larger than 20 kHz. In medical imaging applications, shorter wavelengths corresponding to human tissue as a propagation medium are used, resulting
in frequencies ranging from 2 - 10 MHz, but most commonly between 3 - 5 MHz [3]. A gel-like material used to match the permittivity of human tissue, reducing the loss factor of the signal when changing mediums.

Images are formed using pulse-echo principles where short pulses of ultra-sound waves at these frequencies, and lasting less than 1 µs [4], are output by a transducer that then receives echo pulses from reflections. Using known constants such as the propagation speed in a medium (1540 m/s in human tissue) [3], and arrival time/angles of reflected pulses, a two-dimensional image can be created indicating the distance and shape of an object. Beamforming techniques common in signal processing are used to enhance and layer images to increase resolution and produce 3D/4D imaging [5] by directionally or spatially focusing echo signals received from tissue structures. Weighted delays are applied to these signals to indicate different tissue regions and are summed to form a 3D image. Further algorithms are also applied to estimate attenuation and scattering [6] of pulses to prevent destructive interference from occurring and provide greater resolution to images [7], which are limited by the ultrasound frequencies necessary to image human tissue.

Another imaging technique, used specifically to monitor blood flow, is the Doppler imaging. The Doppler effect, which states moving objects exhibit changing frequency, characterizes Doppler imaging, and this changing frequency results in a shift that can be continuously compared to a reference signal to represent blood flow. Doppler shifts are commonly used to image blood flow from ultrasound pulses at 5 MHz [3].

**Implementation**

Ultrasound imaging is realized through the use of electro-acoustic transducer arrays to send and receive ultrasound pulses from various locations. A full system connects the array to a variable gain amplifier and an analog-to-digital converter (ADC) to generate a usable signal for processors to interpret [8]. DSPs handle beamforming and spectral/color/power Doppler processes implemented in software. These processors require higher bandwidth at 1 GHz or above. An operating system (OS) is necessary for the front-end processing algorithms to increase resolution and is usually paired with the user interface on a processor such as an ARM9. PCBs cost can be lowered by adding an LVDS interface between the ADC and DSP for beamforming, reducing the number of interface lines into the DSP [8]. A gel-like material with permittivity close to that of human tissue is also necessary in obtaining high-resolution images.
References


