ULTRASOUND IMAGING SYSTEM FOR DIAGNOSTIC APPLICATIONS

PROJECT REPORT

EMBEDDED SYSTEMS

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CANDIDATE’S DECLARATION

I hereby certify that the work for project “**ULTRASOUND IMAGING SYSTEM FOR DIAGNOSTIC APPLICATIONS”** submitted to the Department of Electronics & Communication Engineering of Delhi Technological University, is an authentic record of my own work. The matter represented in this report has not been submitted by me for award of any other degree for this or any other institute/university.

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ACKNOWLEDGEMENT

It Is Indeed a Great Pleasure and a moment of immense satisfaction for us to express our gratitude towards Prof. Indu for her priceless help and moral support during the completion of the project. We would like to extend our thanks to her for their valuable help during the project.

We would also like to thank friends and all the people who directly or indirectly have contributed to the completion of this project.

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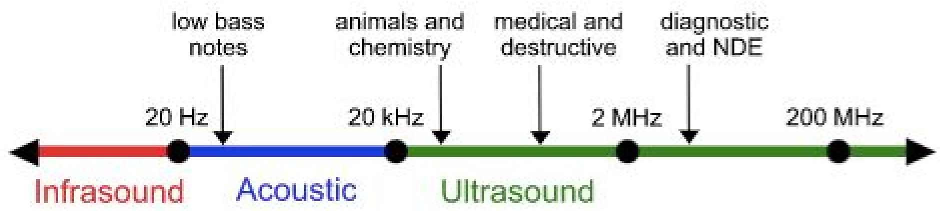
ABSTRACT

Ultrasound Imaging is a diagnostic imaging technique using ultrasound waves. We use it to visualize subcutaneous body structures like tendons, muscles, joints, vessels and internal organs such as heart, kidney etc for possible pathology or lesions. It is possible to perform both diagnosis and therapeutic procedures using ultrasound imaging. Ultrasound Imaging uses the interaction of sound waves with living tissue and produces an image of the tissue or determines the velocity of a moving tissue, primarily blood. The real-time images are analyzed to obtain structural and functional information from the target organ.

Diagnostic ultrasound is an imaging method that uses high-frequency sound waves to produce images of structures within the body. Images can provide valuable information for diagnosing and treating a variety of diseases.

Introduction

Ultrasound is acoustic(sound) energy in the form of waves having a frequency above the human hearing range(i.e. 20KHz) It is a way of using sound waves to look inside the human body.The term "ultrasound" applies to all acoustic energy with a frequency above the audible range of human hearing. The audible range of sound is 20hertz-20kilohertz.



Typical diagnostic sonographic scanners operate in the frequency range of 2 to 18 megahertz. The above frequencies are hundreds of times greater than the limit of human hearing, which is typically accepted as 20 kilohertz. Sonography is effective for imaging soft tissues of the body. Superficial structures such as muscles, tendons and the neonatal brain are imaged at a higher frequency around 7-18 MHz, which provides better axial and lateral resolution. Deeper structures such as liver and kidney are imaged at a lower frequency 1-6 MHz with lower axial and lateral resolution but greater penetration. The velocity of ultrasound waves is identical to that of sound waves in the same medium. In Air, it is 331 m/s, and in body tissues, it ranges from 1540 m/s to 1580 m/s depending on the type of tissue. A velocity of 1,540 m/s is generally used for soft tissue in sonographic imaging and represents an average of that for a number of tissues, muscles and organs. Ultrasound waves are generally produced in pulses for sonographic imaging, with the time interval between pulses used to detect ultrasound echoes produced within the body. Pulse Echo Principle is used to generate Ultrasound in imaging.The length of time taken for the pulse, once produced by the transducer, to travel to the interface and the echoed pulse to return is termed the pulse echo time. Pulse echo time can be calculated using the formula:

$$t=2d / -V$$

Where t is the pulse echo time, d is the depth.

Ultrasound Imaging Method

It is done in three steps

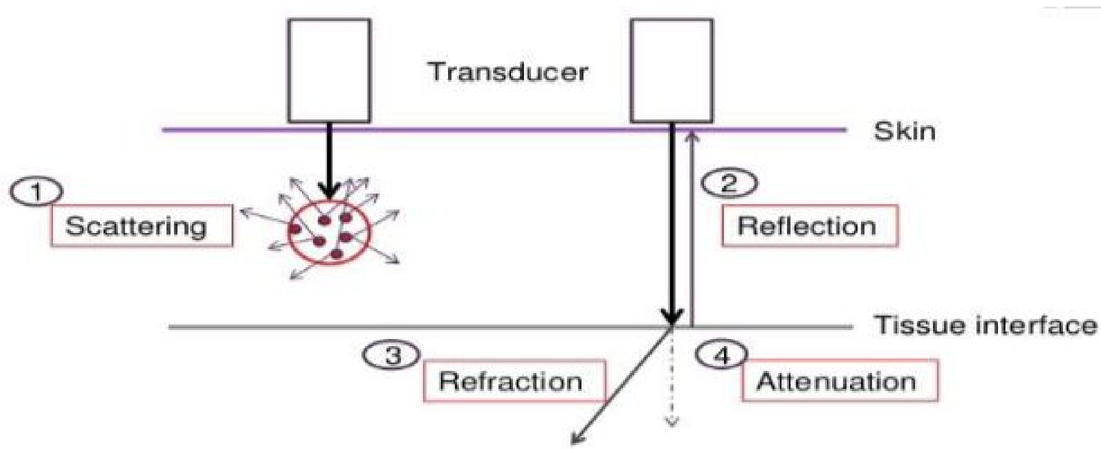
- Ultrasound production: The Ultrasound wave is typically produced by a piezoelectric transducer encased in a housing which can take a number of forms. Strong, short electrical pulses from the ultrasound machine make the transducer ring at the desired frequency. The frequencies can be anywhere between 2 and 18 MHz. The sound is focused either by the shape of the transducer, a lens in front of the transducer, or a complex set of control pulses from the ultrasound scanner machine. This focusing produces an arc-shaped sound wave from the face of the transducer. The wave travels into the body and comes into focus at a desired depth. Materials on the face of the transducer enable the sound to be transmitted efficiently into the body. In addition, a water-based gel is placed between the patient's skin and the probe. Ultrasound Scanner Probe Ultrasound transducers exploit the piezoelectric effect to cause a crystal to vibrate at ultrasound frequencies. The resultant vibrations generate pulses of compressions and rarefactions which propagate through the tissues. Echoes produced by tissue interfaces are then detected by the same crystal exploiting the piezoelectric effect once again. The ultrasound pulse becomes attenuated as it passes through tissue. The switch array is used to excite the multiple crystals in the transducer. In the simplest arrangement, each crystal generates an ultrasound pulse one after the other so that sequential lines of tissue can be rapidly and continuously insonated. Some of the energy in the pulse is scattered through a process called non-specular reflection, some of it generates an echo in a specular reflection process, some of it is transmitted through the interface to produce further echoes at other interfaces and a small amount is absorbed. The reflectivity of an interface depends on the acoustic impedance of the two tissues involved. The sound wave is partially reflected from the layers between different tissues. Specifically, sound is reflected anywhere there are density changes in the body: e.g. blood cells in blood plasma, small structures in organs, etc. Some of the reflections return to the transducer. The scanner operates using a linear array transducer. The Master timer circuit sets the number of ultrasound pulses which the transducer generates every second. This is referred to as the Pulse Repetition Frequency (PRF)

- Echo reception: The return of the sound wave to the transducer results in the same process that it took to send the sound wave, except in reverse. The return sound wave vibrates the transducer; the transducer turns the vibrations into electrical pulses that travel to the ultrasonic scanner where they are processed and transformed into a digital image.The echo pulses are picked up by the transducer and are amplified by a Receiver Amplifier whose output is demodulated before being fed to a Scan Converter so that the location and amplitude of detected echoes can be displayed. The Time-Gain Compensation (TGC) circuit provides for selective amplification of the echo signals so as to compensate for attenuation of distant ultrasound echoes and suppress more proximal ones.
- Ultrasound image: The ultrasound image is known as B-Mode scan and it consists of a 2D representation of the echo pattern in a cross-section of tissue with the transducer position at the top of the image. The locations of echo-producing tissue interfaces are

generally represented by bright pixels on a dark background, with the amplitude of each echo signal being represented by the pixel value. Ultrasonography Image Images from the sonographic scanner can be displayed, captured, and broadcast through a computer using a frame grabber to capture and digitize the analog video signal. The captured signal can then be post-processed on the computer itself.

Ultrasound Imaging Principle

Ultrasound waves are created by a vibrating crystal within a ceramic probe. Waves travel through the tissue and are partly reflected at each tissue interface. "Piezoelectric " principle- electric current causes crystals to vibrate, returning waves create electric current. When ultrasound propagates through matter reflection, refraction, diffraction, attenuation, scattering occur. The greater the acoustic mismatch or difference in tissue densities, the more sound waves are reflected and returned to the transducer. Areas with relatively large tissue density differences, and hence more reflected sound waves, are generally seen as brighter areas on the final image. As a result of these properties, ultrasound imaging is best suited for soft tissue imaging and is often limited by bone- and gas-filled structures. Sound is transmitted rapidly through bone tissue. Conversely, sound is poorly transmitted through air and air filled structures. The large acoustic impedance mismatch that occurs at bone and gas interfaces with soft tissue causes the majority of sound waves to be reflected. This large reflection decreases sound wave penetration into deeper tissues and can cause imaging artifacts.



Despite this limitation, specialized techniques have been developed to perform transcranial Doppler imaging of the cerebral vasculature in humans and dogs. Resolution, or the ability to distinguish two closely situated structures or events accurately, is an important concern for all imaging methodologies. However, resolution becomes even more important when imaging small targets such as rat and mouse organs. For example, the left ventricular chamber diameter of a mouse heart is 2 to 3 mm and the LV posterior wall is approximately 0.6 mm thick at end diastole. In rodent ultrasound imaging, both spatial and temporal resolution must be considered. Spatial resolution is further divided into axial and lateral resolution. Axial resolution is the ability to distinguish two separate but closely positioned structures situated parallel to the propagation axis of the ultrasound beam. Axial resolution is dependent on sound wave pulse length and frequency. Two structures will be seen as separate structures only if the pulse length is shorter than the distance between the structures. If the pulse length is longer than the distance between the structures, only a single reflection will be detected and the image will show only one structure. Higher frequency sound waves have shorter pulse lengths and generally greater axial resolution. Lateral resolution refers to the ability to distinguish two adjacent but separate structures oriented perpendicularly to the axis of the sound wave beam. Lateral resolution is dependent on beam width and sound wave frequency. Narrower beam width provides greater lateral resolution. Beam width can be minimized by focusing the sound waves as they are produced by the transducer. In most ultrasound systems, beam focusing is performed by curving the elements of the transducer or by electronically controlling the elements of the transducer. Lateral resolution is also influenced by the frequency of the sound wave, with higher frequencies generally improving resolution. Because axial and lateral resolution improves with increasing frequency, higher frequency transducers are generally preferred for rat and mouse imaging. Rat hearts have been imaged using a variety of ultrasound systems with transducers operating at frequencies from 5 to 12 MHz.

Block Diagram of Ultrasound Imaging System

It consists of following parts:

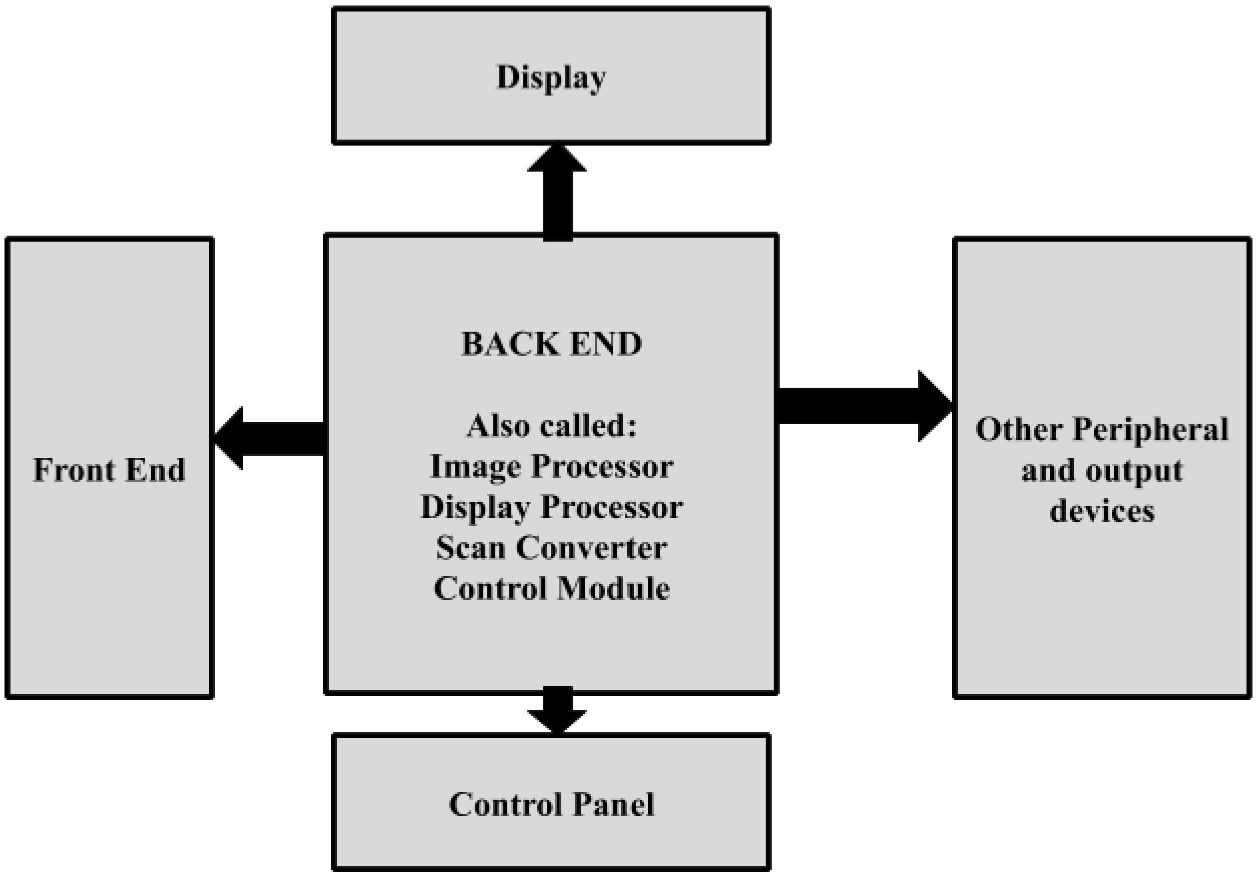
1. Display (System monitoring): HD11 system monitor is an RGB, 15-in FST display monitor. It has an integrated microphone and supports six different video formats.

2. Backend System: This part is used to process the images of tissues or other living parts captured by the help of ultrasound waves. This part is also known by several other names such as Image Processor or Display Processor or Scan Converter or Control Module

3. Front End System: It is also known as acquisition module or Beam former or scanner. It synchronizes the generation of ultrasound waves, focuses on the transmitted beam, amplifies the returning echoes and compensates for attenuation.

4. Control Panel: It mainly consists of user input peripheral devices such as keyboard, trackball, microphone, foot switch, touch panels.

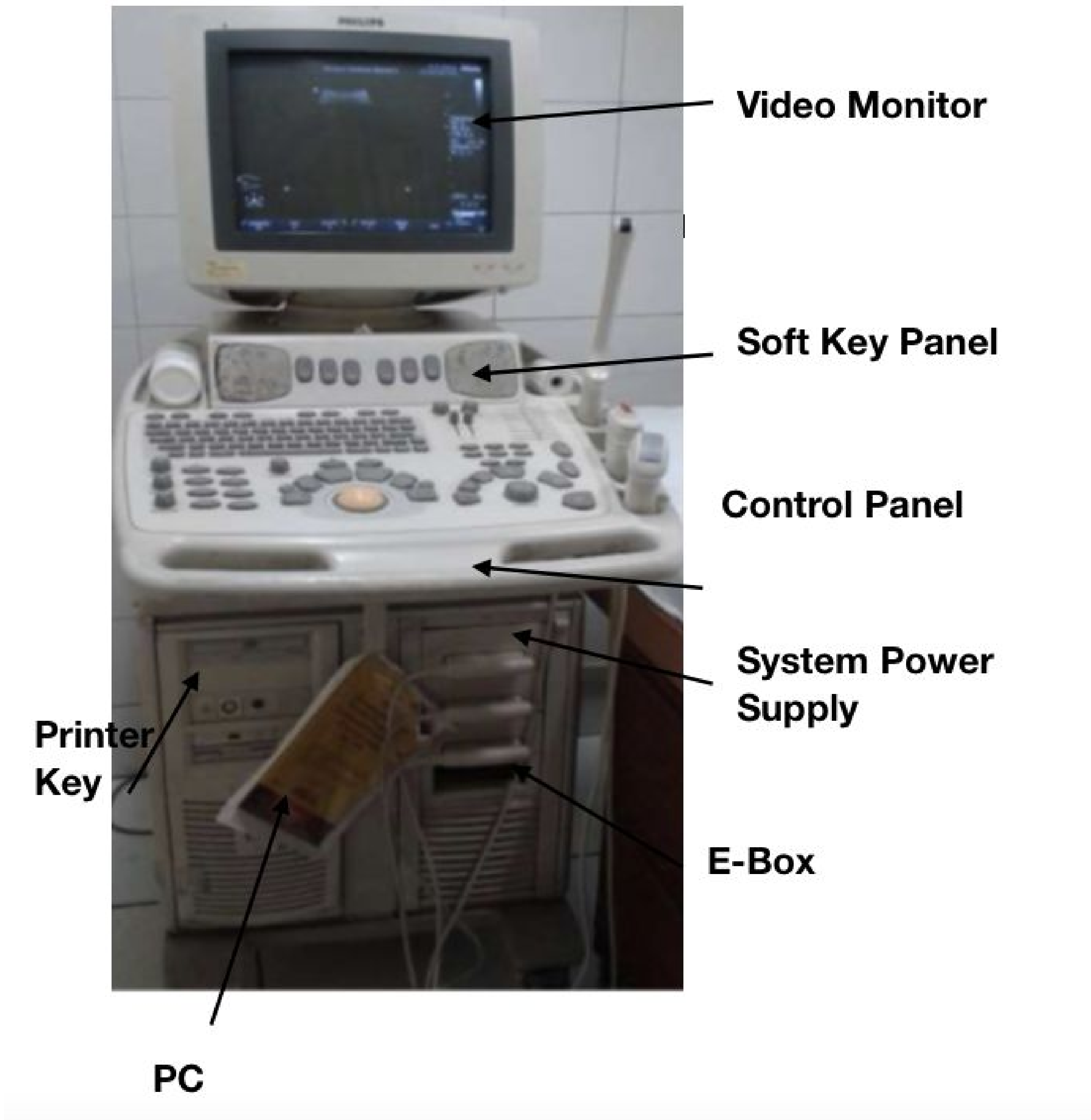
5. Other Peripherals and Output devices: It includes printers, speakers networks and other ports.



General components of Imaging System

Hardware Architecture: It consists of an E BOX and personal computer (PC)

- E Box: It has electronic boards that perform many ultrasonic imaging functions such as transducer selection, beam forming, detection and image processing. The various electronic boards are: System motherboard (backplane), Signal distribution board, Four TR boards (TR0, TR1,TR2 and TR3), Signal processor board.
- Personal computer (PC): It acts as a central processing unit. It performs processing of image data and serves as a main controller of the E-Box and system user interface.



Software Architecture: It consists of four major executables:

- Beam processing control (E Box)
- Signal processing control (E Box)
- Image modalities (PC)
- Image management and review (PC)

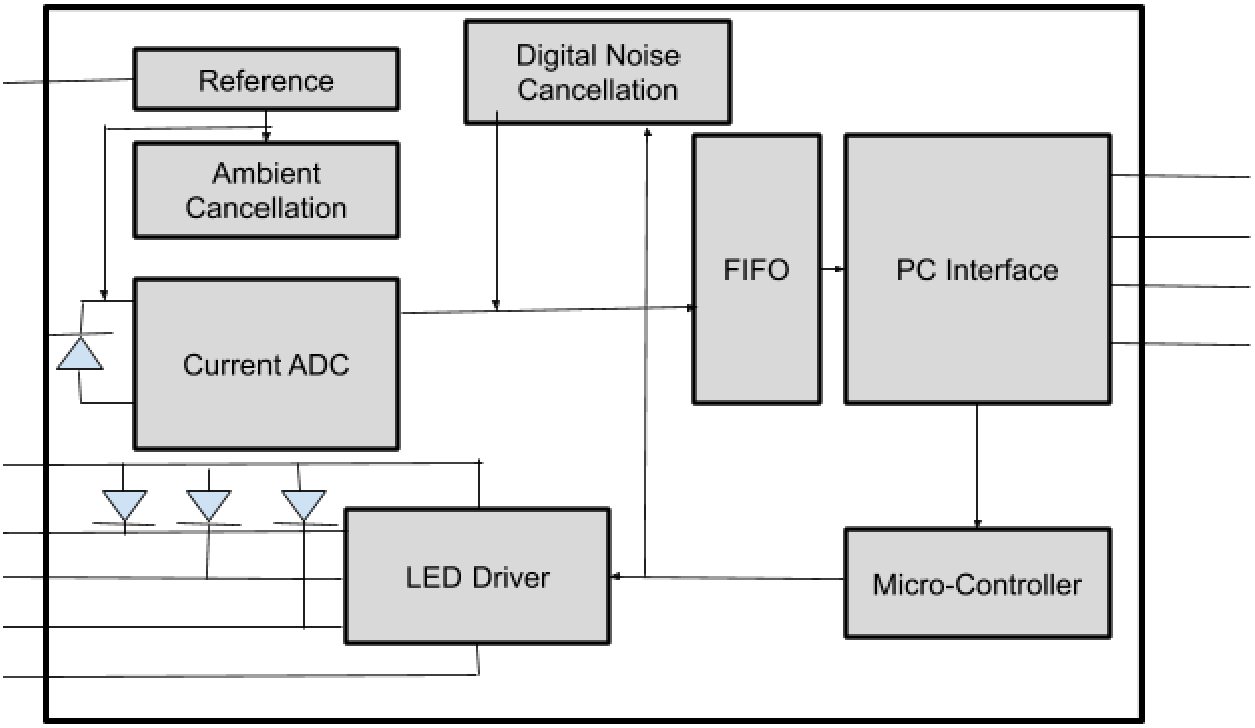
- Beam processing control (E Box) : It is a common signal processor used to create directional or spatial selectivity of signals sent to or received from an array of sensors or antennae. These arrays can be found in many different devices that transmit and receive either electromagnetic or acoustic waves. Thus, beamforming is employed in such varied applications as radio-astronomy, radar, wireless communications, sonar, seismography, and medical and industrial ultrasound. Ultrasound beamforming is unique among these various applications. In order to achieve high-quality ultrasonic images, received beams must be focused dynamically, and the aperture of the array must be amplitude-weighted (apodized) dynamically as well. In most beamformer applications, such as in phased-array radar or radio telescope arrays, the distance to the reflector (e.g. an aircraft or a distant galaxy) is large compared to the aperture or length of the antenna or transducer array. In these systems the receiver is primarily concerned with capturing reflections in the farfield. These systems use the array to steer the beam in the needed direction, but can perform static beam focusing with a focal point set at infinity.

- Signal processing control (E Box): It provides functions and apps to analyze, preprocess, and extract features from uniformly and nonuniformly sampled signals. With the Signal Analyzer we can preprocess and analyze multiple signals simultaneously in time, frequency, and time-frequency domains, explore long signals and extract regions of interest

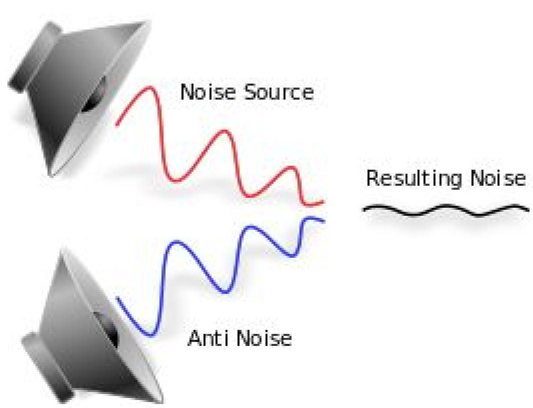
- Image modalities (PC): . This imaging method extracts and displays certain selected features based on different physical attributes of tissues. Ultrasound imaging reveals the mechanical structures of tissue in real-time and Doppler ultrasound measures the dynamic flow of blood.

- Image management and review (PC): It is an image management system for use in conjunction with an ultrasound machine. The system comprises an input port coupled to the ultrasound machine for receiving the video output signal generated for the ultrasound images and a frame buffer for digitizing and storing the video output from the ultrasound. It includes a switch for routing the video output signal or the video signal generated from the digitized ultrasound images to the monitor of the ultrasound for display and allows the original video signal to be displayed without introducing artifacts. The system includes storage devices for archive and retrieval of the digitized ultrasound images and playback on the ultrasound monitor. It also includes a communication port for interfacing the ultrasound with a PACS or a networked ultrasound management system.

Architectural Design of Ultrasound Imaging System



- Ambient Cancellation: It is used for cancelling ambient or background noise from the environment. Sound is a pressure wave, which consists of alternating periods of compression and rarefaction. A noise-cancellation speaker emits a sound wave with the same amplitude but with inverted phase (also known as antiphase) to the original sound. The waves combine to form a new wave, in a process called interference, and effectively cancel each other out – an effect which is called destructive interference.



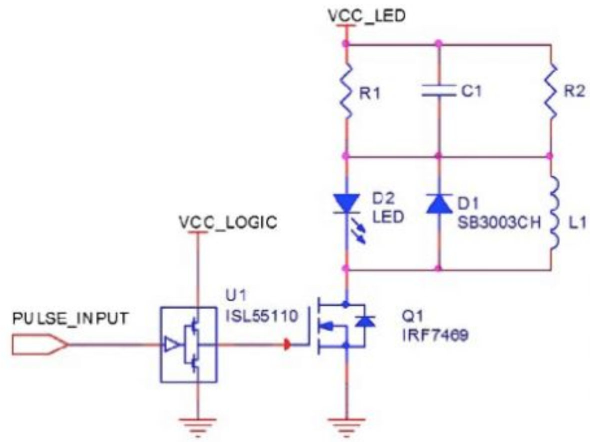
- Digital Noise Cancellation: Just like with sound, where noise refers to auditory disruptions, in image processing applications, the term digital noise refers to visual distortion. Noise looks like tiny colored pixels or specks in the image. This noise can distort the visual detail of the image. Several factors can affect the level of noise, including sensor size, higher ISO settings, and long exposures, to name a few.

  One method to remove digital noise is by convolving the original image with a mask that represents a low-pass filter. For example, the Gaussian mask comprises elements determined by a Gaussian function. This convolution brings the value of each pixel into closer harmony with the values of its neighbors. In general, a smoothing filter sets each pixel to the average value, or a weighted average, of itself and its nearby neighbors; the Gaussian filter is just one possible set of weights. Basic Digital Image filters like Gaussian averaging, mean, median, Local Region filter, Lee and Diffusion Filter, Wiener filter are applicable to ultrasound images for reducing noise.Current ADC.

- Current ADC: A current analog-to-digital converter (ADC) is a system that converts an analog current signal into a digital one. An ADC may also provide an isolated measurement such as an electronic device that converts an input analog current to a digital number representing the magnitude of that current.Many ADCs used in Ultrasound applications are: 24-Bit Multi-Channel Low-Power 1.9ksps Delta-Sigma ADC, Tiny Serial 12-Bit ADC, 16-Bit Multirange ADC with PGA and Reference etc. It acts as a central processing unit.

- PC Interface: It performs processing of image data and serves as a main controller of the E-Box and system user interface. One of the PC Interfaces used is Octal Power and Energy Measurement IC.

- LED Driver: LED driver is required to convert the alternating current from the power supply to the regulated voltage direct current used by the LEDs. LED drivers used for ultrasound imaging are 2A Synchronous Buck LED Driver with Integrated MOSFETs, Automotive High-Voltage, High-Brightness LED Controller etc. Its circuit diagram can be shown as:



- <u>FIFO (First In First Out Technology):</u> In every digital system, data is continually being exchanged between various subsystems. Intermediate storage is always necessary if data arrives at the receiving subsystem at a high rate or in batches but can then only be processed slowly or irregularly.An intermediate store or memory that operates on the above principle is known as a first-in, first-out (FIFO) memory. The first data written into a FIFO is also the first to leave it at readout. Some FIFOs used in microcontrollers are 12-Bit 300ksps ADCs with FIFO, SPI/I²C UART with 128-Word FIFO etc.

- <u>Micro-controller:</u> In ultrasound imaging applications microcontroller platforms can lead to great results at a very low cost, high-frequency microcontrollers have proven quite effective in generating ultrasonic images. Some ultrasonic systems are based on raspberry pi and PIC32 microcontrollers. Some microcontrollers and their applications are as follows:

    - ❖ MAX32520-KIT: Cortex®-M4 secure microcontroller provides secure boot and protection against physical tampering for IoT applications.
    - ❖ MAX32620-EVKIT: Ultra Low power microcontroller
    - ❖ MAX32590 High-performance, single-chip secure microcontroller with encrypted external bus and advanced physical security.
    - ❖ Optical Microcontroller: This is a 16-bit microcontroller with a unique peripheral set supports optical applications that require high-resolution conversion of many analog signals and digital signal processing (DSP) of those signals, high-speed data communication to an external host, and ultra-low power dissipation.

Diagnostic Applications of Ultrasound Imaging System

In the field of obstetrics and gynecology:

- Measuring the size of the fetus
- Determining the sex of the baby
- Monitoring the baby for various procedures

In the field of cardiology:

- Seeing the inside of the heart to identify abnormal function
- Measuring blood flow through the heart and major blood vessels

In the field of Urology:

- Measuring blood flow through the kidney
- Locating kidney stones
- Detecting prostate cancer at early stage

Risks involved in using Ultrasound Imaging System

The two major risks involved with Ultrasound are:

- Development of heat: Sometimes tissues or water absorb the ultrasound energy which increases their temperature locally, leading to development of heat.
- Formation of bubbles (cavitation): When dissolved gases come out of solution due to local heat caused by Ultrasound, bubbles are formed.

Benefits of using Ultrasound Imaging System

- It images muscles and soft tissues very well.
- Ultrasound systems render live images where the most desirable section is selected.
- It shows the structure of organs.
- It has no long-term side-effects.
- It is widely available,comparatively flexible, relatively inexpensive and highly portable.
- It’s spatial resolution is better in high frequency ultrasound scanners.

Limitations of using Ultrasound Imaging System

- Ultrasound Imaging devices have trouble penetrating bone.
- It performs very poorly when there is a gas between the transducer and organ of interest.
- Body habitus has a large influence on image quality.
- This method is operator-dependent.