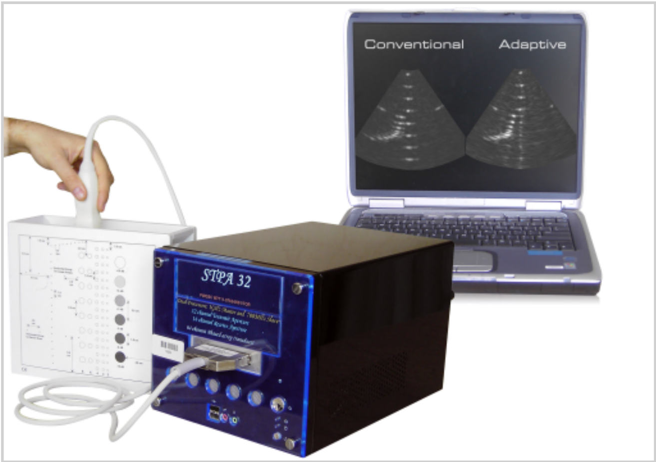
This unit is a fully digital 3D ultrasound portable system that provides superior image resolution at minimal cost



Portable 3D Ultrasound System with standard ultrasound phantom

See demo images

See introduction video

These are fully digital systems including synthetic aperture and adaptive beam forming techniques to provide superior image resolution and quality

Overview

These systems are based on adaptive beam forming technology which provides a high resolution imaging system with minimal hardware complexity, introducing the concept for the next generation real-time fully digital volumetric ultrasound systems.

Coded transmit pulse design allows illumination of the entire region of interest with fewer active illuminations, yielding higher frame rates and more robust focusing capabilities.

The 2D/3D Portable Ultrasound System

- *Based on a line array probe*
- *Uses phased array techniques for illumination and beam forming*
- *Features B-scan mode and automated 3D mode*
- *Includes full volume visualization*

The 3D/4D Volumetric Ultrasound System

- *Based on a dense planar array probe, using phased array techniques*
- *Enhances software implementation of the 3-D beam forming*
- *Easily implemented on a multi-node processing system*
- *Includes full 3D visualization*

Areas of Application

- *Prenatal Imaging*
- *Cardiac Ultrasound Imaging*
- *Real-Time and Interactive Volume Visualization*
- *High Resolution Examinations*
- *Organ Studies*

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Real-Time 2D/3D Ultrasound Adaptive Beamforming Technology

System Concept

The development of the experimental 2D/3D ultrasound system is based on adaptive ultrasound beamforming technology. This provides a concept demonstration of a high image resolution system with minimum hardware complexity.

The uniqueness of this technology is that it improves the detection and image resolution performance of general purpose ultrasound systems as well as those deployed for image guided surgery and treatment by replacing their current beamformers with an adaptive beamforming structure. These adaptive beamformers are characterized by high image resolution that is equivalent to that of larger-aperture ultrasound probe arrays.

Background

Even the most-advanced state-of-the-art medical ultrasound imaging systems suffer from very poor image resolution, which is the result of the very small size of deployed arrays of sensors and the distortion effects caused by the human-body's non-linear propagation characteristics. In particular, some of the limitations (e.g. resolution) of ultrasound imaging are related to fundamental physical aspects of the ultrasound transducer and the interaction of ultrasound with tissues (eg. aberration effects).

A state-of-the-art transducer array of an ultra-sound system is either linear or curvilinear depending on the application; and for each deployed array, the number of transducers is in the range of 96 to 256 elements.

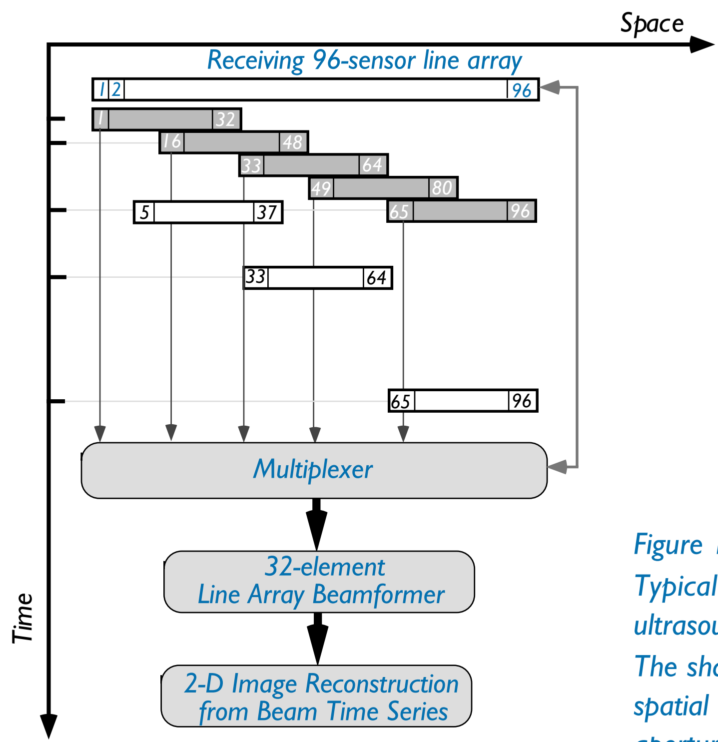

Figure 1:
Typical beamformers for linear arrays of ultrasound systems.
The shaded sub-apertures indicate the selected spatial locations for the formation of synthetic aperture according.

However, only a small number of transducers of a given array are beamformed coherently to reconstruct an image of interest [3]. A typical number of transducers that may be used in the beamforming structure of an ultrasound system are in the range of 32 to 128 elements. Thus, the system array gain would be smaller than the gain available by the full deployed array by approximately 5 dBs (10xLog10 (3) 5 dBs) . Figure 1 illustrates the basic processing steps associated with the ultrasound beamforming process. In the example in the Figure 1 the array is considered to be linear with 96-elements, subsets of which can be used to transmit and receive signals. As shown in Figure 1, for each active transmission, the ultrasound beamformer coherently processes the received signal of 32-elements only, which is a sub-aperture of the 96-element deployed array.

Assume that the energy transmission takes place approximately every tau = 0.3ms, varying depending on the desired penetration depth in the body. The beam steering process is at the broadside. When a transmission is completed, the receiving 32-element sub-aperture is shifted to the left and repeated, as shown in Figure 1.

Thus, to make use of all the 96-elements of the deployed array, the 32-element beamforming process is repeated 64 times, generating 64 broadside beams. In other words, it would take approximately 64x0.3 ms 20 ms to reconstruct a 2-D tomography image of interest. As a result, the resolution characteristics of the reconstructed image are defined by the array gain of the beamformer and the temporal sampling of the beam or element time series. In the specific case of Figure 1, the pixel resolution along the horizontal x-axis of a reconstructed tomography image is defined by the angular resolution along azimuth of the 32-element beamformer, and also by detector spacing. This resolution limitation due to larger detector spacing is usually artificially improved by means of interpolation, which defines the basic difference between beamformers of different ultrasound systems.

The pixel resolution along the vertical y-axis of the image generated is defined by the sampling rate, which is usually very high and it is not a major concern in ultrasound system applications. Thus, improvements of image resolution in ultrasound system applications requires mainly higher angular resolution or very narrow beamwidth, which means longer arrays, with longer sub-apertures, and smaller detector spacing, for the beamforming process. This brings with it the consequent technical and operational implications and higher system manufacturing cost.

The main advantages of this simplified beamforming structure are the following:

- *The generation of broadside beams allows the use of frequencies that are higher than the corresponding spatial-aliasing frequency of the sensor spacing of the ultrasound probe. This is because side-lobe artifacts due to spatial aliasing are insignificant for beams steered to broadside.*
- *The advantage (suppression of spatial-aliasing artifacts) provided by the broadside beam-steering process has been used effectively by illumination techniques using higher order-harmonics to achieve deeper penetration with corresponding higher image resolution along the temporal axis.*
- *The field of view of the probe may be larger than the active aperture size required by the broadside beamformer. This approach minimizes the hardware complexity of the A/DC by using a multiplexer to control the data acquisition process of a probe with a larger number of sensors than those being used by the broadside focus beamformer. In the example of Figure 1, there total size of the aperture in 96 elements, but since only 32 elements are active at any given time, only 32 channels needs to be connected, and they can be selected by multiplexing.*

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- The field of view of the probe may be larger than the active aperture size required by the broadside beamformer. This approach minimizes the hardware complexity of the A/DC by using a multiplexer to control the data acquisition process of a probe with a larger number of sensors than those being used by the broadside focus beamformer. In the example of Figure 1, there total size of the aperture in 96 elements, but since only 32 elements are active at any given time, only 32 channels needs to be connected, and they can be selected by multiplexing.

Uniqueness of CANAMET's Ultrasound System Innovation

CANAMET's adaptive beamforming ultrasound imaging technology leads to a next-generation high-resolution real 2D and 3D diagnostic imaging system that consists of:

- Synthetic aperture processing for linear arrays including 2D phased array beamforming
- Adaptive beamforming to effectively increase angular resolution
- 2D and 3D visualization schemes integrated with the ultrasound adaptive beamformer and synthetic 3D volume rendering from 2D imaging

Visualization Technology

The integration of the 2D/3D visualization technology components with CANAMET's 2D adaptive beamforming structure is essential to achieve complete system functionality, as was defined above. The main characteristics of a target visualization package are summarized below:

- It visualizes the 3D data collected from the U/S system in a fast and flexible manner, without compromising image quality, enabling a comfortable and effective user interface to the system.
- It creates a natural interface to the collected data for off-line examination, educational and for telemedicine applications.
- It enables communications of medical data, most of which are pictorial in nature for remote consultation/education among doctors, and between doctors and their students and patients.

The methods include Real-time volume visualization that includes tools for parameter extraction such as 3D measurements, volumetry, wall motion, etc. Remote visualization refers to an interactive visualization process acted on large data sets at remote sites via Internet or other communication links. Remote visualization has becoming a hot topic in telemedicine research. One way to maximize the utility of state-of-art expensive medical imaging systems and large valuable image databases is to allow remote access to these resources.

References

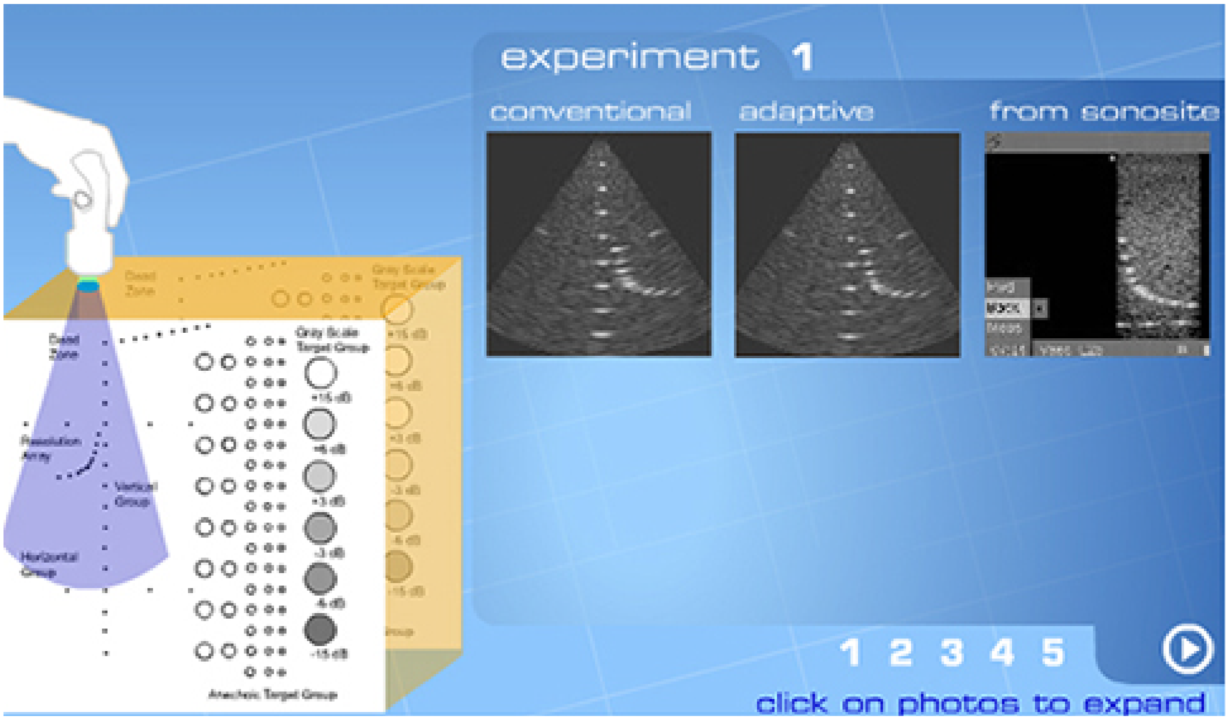
[1] S. Stergiopoulos, "Implementation of adaptive and synthetic aperture processing schemes in integrated active-passive sonar systems", Proc. IEEE, 86(2), 358-396, Feb.-98.

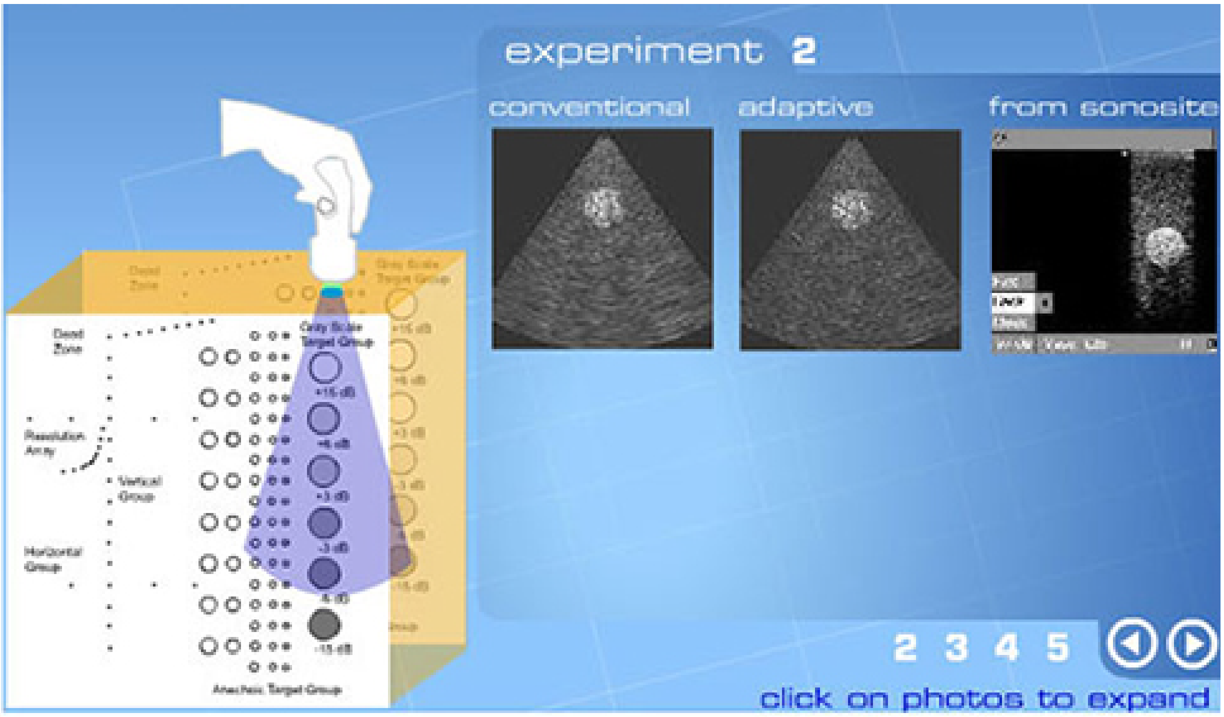
[2] B. Van Veen and K. Buckley, "Beamforming: as Spatial Filtering", IEEE ASSP Mag., pp. 4-24, 1988.

[3] S. Stergiopoulos, "Advanced Beamformers", Chapter 6 in Handbook on Advanced Signal Processing for Sonar, Radar and Medical Imaging Systems, CRC Press LLC, Boca Raton, FL, Dec- 2000.

[4] Stergios Stergiopoulos and Amar Dhanantwari, "High Resolution 3D Ultrasound Imaging System Deploying a Multi-Dimensional Array of Sensors and Method for Multi-Dimensional Beamforming Sensor Signals" issued 19 November 2002 US 6,482,160

System demonstration with standard Ultrasound phantom





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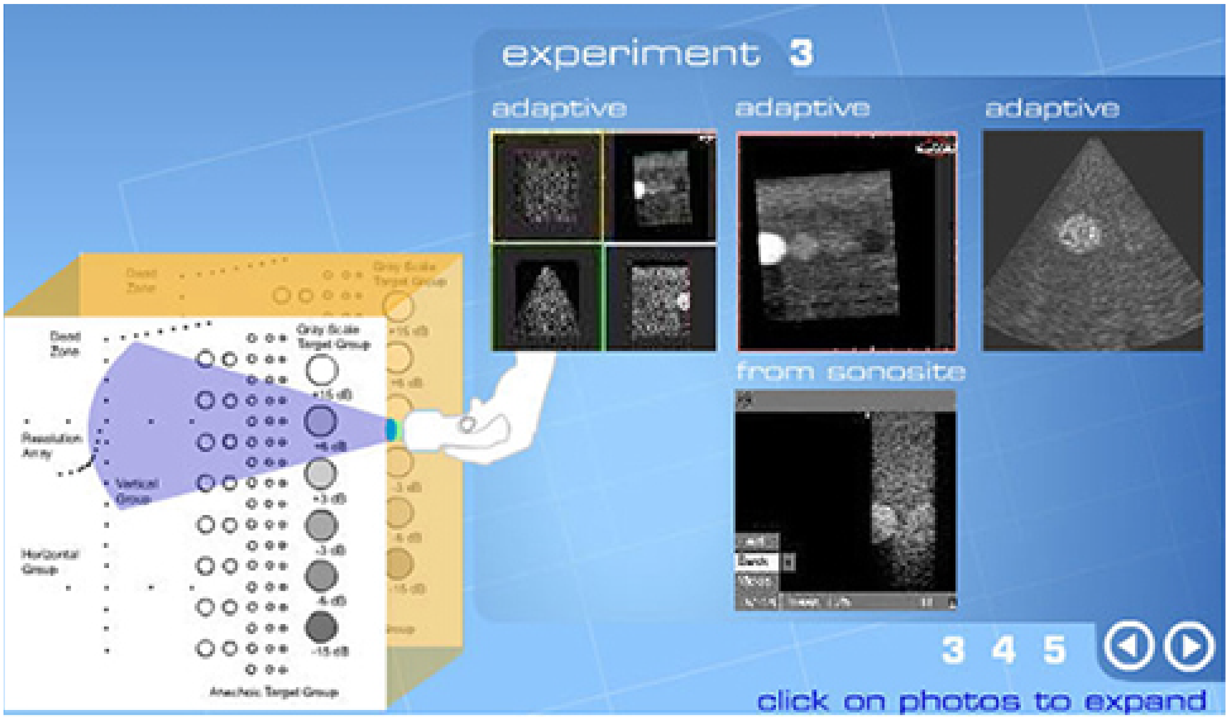

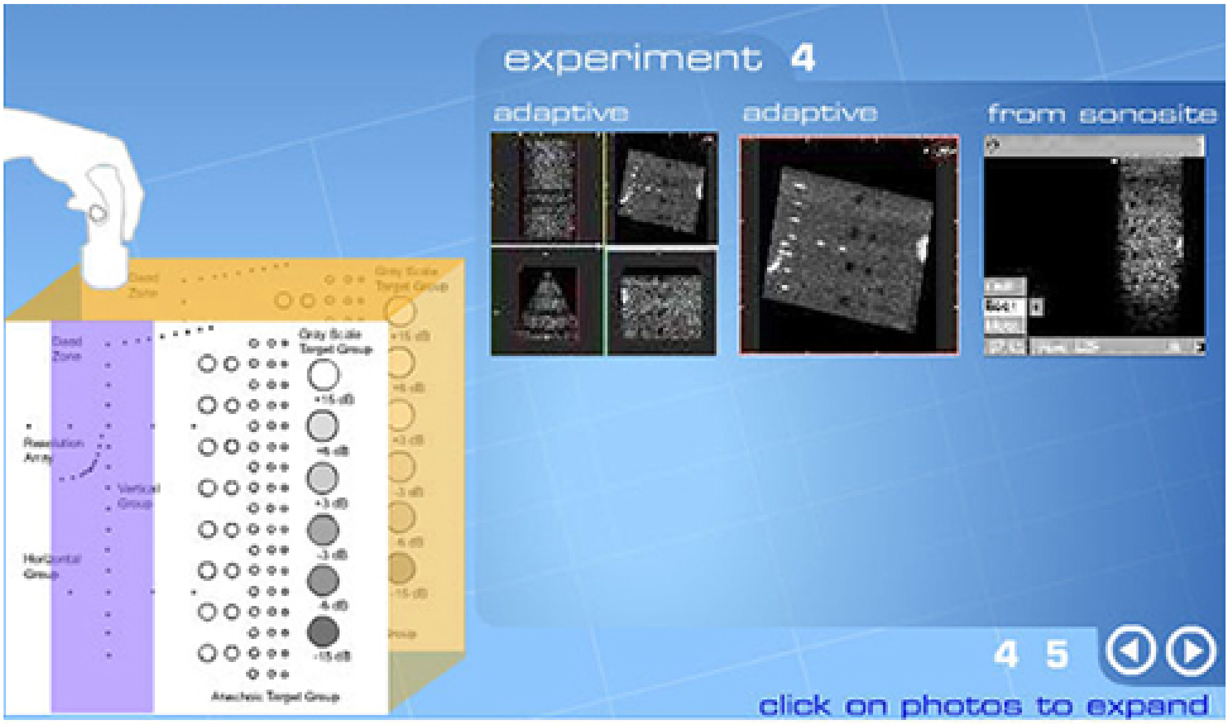

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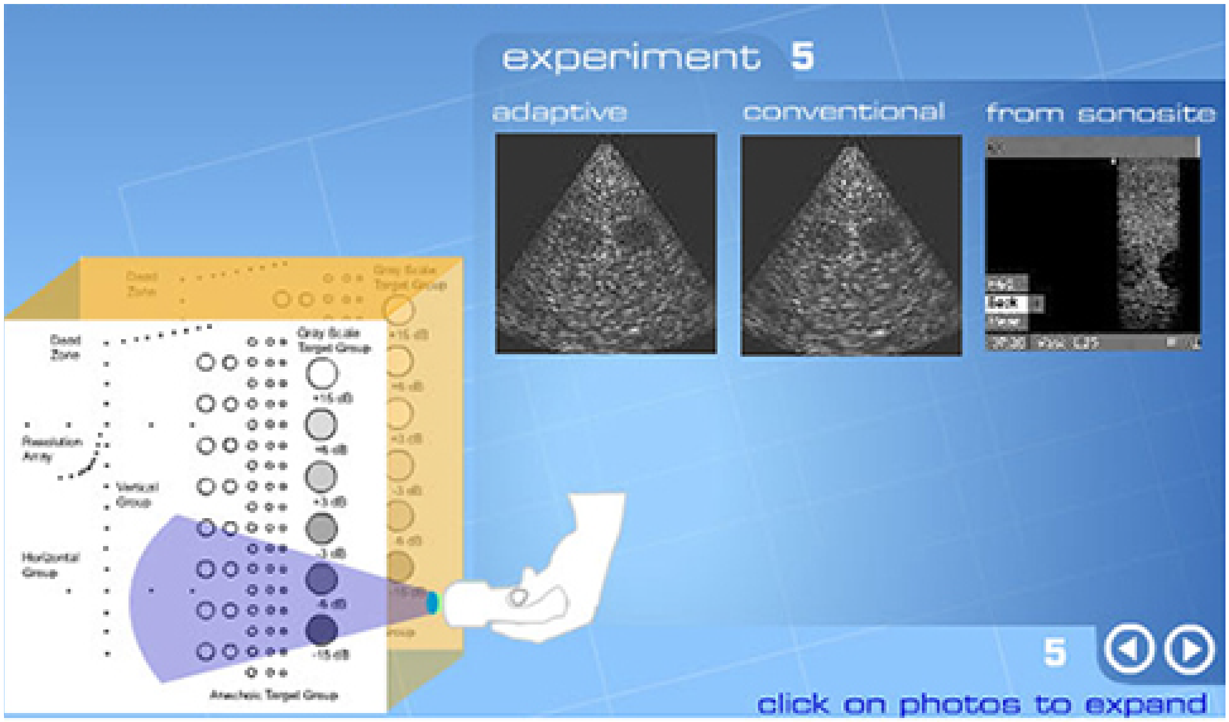

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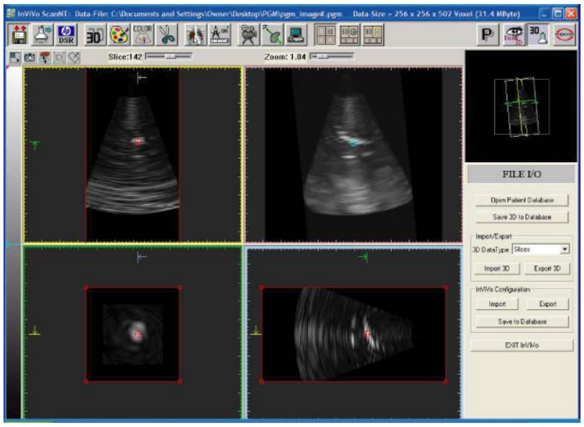

Real-Time 3D/4D Ultrasound Technology with Adaptive Beamforming

System Concept

The concept is centered on developing an ultrasound system that is based on multidimensional beamforming, specifically for planar arrays, and the inclusion of adaptive ultrasound beamforming technology. This introduces the concept for the next generation real-time, fully digital volumetric (4D = 3-Dimensional + 1-D Temporal) ultrasound technology. Also it provides a concept demonstration of a computing architecture that handles the processing needs of a 3D/4D ultrasound system.

- *Since this is a major project development, the R&D efforts include*
- *The development of an advanced 3D and 3D adaptive-synthetic aperture ultrasound beamforming signal processing structure that is based on defence sonar technology of the Canadian Department of Nation Defence - DRDC R&D efforts. [1-4]*

A computing architecture development as an embedded system for planar phased array ultrasound probes that is capable of supporting more than 15 G flops sustained throughput and the 2Gbytes/seconds data flow that is necessary for the computationally intensive requirements of the adaptive ultrasound processing structure.

The 3D/4D system comprises of two separate but complementary components: First the adaptive beamforming approach improves image resolution and detection performance in ultrasound system applications by means of advanced signal processing, an approach that improves image resolution with fixed hardware requirements. Second, the deployment of a 2-D (Planar Array) probe, allows for volumetric imaging using Ultrasounds. The unique decomposition method [3,4] allows for an efficient 2-stage implementation of the planar array beamforming process, using standard line array beamforming techniques, or alternatively Canamet's adaptive beamforming techniques.

Background

The requirements for non-invasive and minimally invasive medical diagnostic procedures can be addressed with the development of high-resolution 3D or 4D ultrasound medical imaging systems [3,4,5]. However, even the most-advanced state-of-the-art medical ultrasound imaging systems suffer from very poor image resolution, which is the result of the very small size of deployed arrays of sensors and the distortion effects caused by the human-body's non-linear propagation characteristics. In particular, some of the limitations (e.g. resolution) of ultrasound imaging are related to fundamental physical aspects of the ultrasound transducer and the interaction of ultrasound with tissues (eg. aberration effects) [1-3]. CANAMET's next generation 4D adaptive ultrasound technology addresses the following limitations:

- *Conventional ultrasound images are 2D, hence, the physician must mentally integrate multiple images to develop a 3D impression of the anatomy/pathology during procedure. This practice is time-consuming, inefficient, and requires a highly skilled operator, all of which can potentially lead to incorrect diagnostic and therapeutic decisions.*

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- *Often the physician requires accurate estimation of tumor and organ volume. The variability in ultrasound imaging and volume measurements using a conventional 2D technique is high, because current ultrasound volume measurement techniques assume an idealized elliptical shape and use only simple measures of the width in two views [5]. 3D images will provide means to obtain accurate and precise organ and tumor volume estimates [5].*
- *It is difficult to localize the thin 2D ultrasound image plane in the organ, and difficult to reproduce a particular image location at a later time, making 2D ultrasound a limited imaging modality for monitoring of disease progression/regression and follow-up patient studies.*

Uniqueness of CANAMET's Ultrasound System Innovation

- *CANAMET's adaptive beamfoming ultrasound imaging technology leads to a next-generation high-resolution real 3D/4D diagnostic imaging system that consists of:*
- *Synthetic aperture processing for planar arrays using 3D phased array beamforming*

  adaptive beamforming to effectively increase the angular resolution

  16x 16 or 32x32-sensor planar phased array probe with uniform sensor spacing to achieve maximum sensitivity and allow true, fast and accurate volumetric scanning without mechanical movement of the transducer.
- *3D and 4D visualization schemes integrated with the 3D ultrasound adaptive beamformer.*

The deployment of planar arrays by ultrasound medical imaging systems has been gaining increasing popularity because of its advantage to provide real 3-D images of organs under medical examination. If we consider that a state-of-the-art phased array line array ultrasound system consists of 128 sensors, then a planar array ultrasound system should include at least 128x128 = 16,384 sensors in order to achieve the angular resolution performance of a line array system and the additional 3D image reconstruction capability provided by the elevation beam steering of a planar array. Thus, increased angular resolution in azimuth and elevation beam steering for ultrasound systems means larger sensor arrays, and consequently higher technical and financial costs. It has been shown [3,4] that the alternative is to implement synthetic aperture and adaptive beam processing in ultrasound systems that deploy a planar array with 1024 sensors, which consist of 32 line arrays with 32 sensors each. Then, the anticipated array gain improvements by the adaptive beamformer would be close to those provided by a 96-sensor line array for azimuth beam-steering and a 96-sensor vertical line array for elevation beam steering for real 3D ultrasound imaging. In summary, the array gain improvements for an adaptive 1024-sensor planar array would be as much as that could be provided by a conventional 96x96 = 9216-sensor planar array. This is because for line arrays, our preliminary quantitative assessment shows the image resolution improvements of the proposed advanced beamformers to be equivalent to a two to three time longer physical aperture. To address this requirement and to allow for a flexible system design for planar array ultrasound systems, CANAMET's industrial development has developed an advanced beamforming structure for planar arrays. Figure 2 shows the steps involved in decomposing the 2-D planar array beamformer into two steps of line-array beamformers [3,4]. The decomposition of the planar array beamformer into these two line-array beamforming steps leads to an efficient implementation based on the following two factors. First, the number of the involved sensors for each of these line array beamformers is much less than the total number of sensors, of the planar array. This kind of decomposion process for the 2-D beamformer eliminates the need for very large real time system application.

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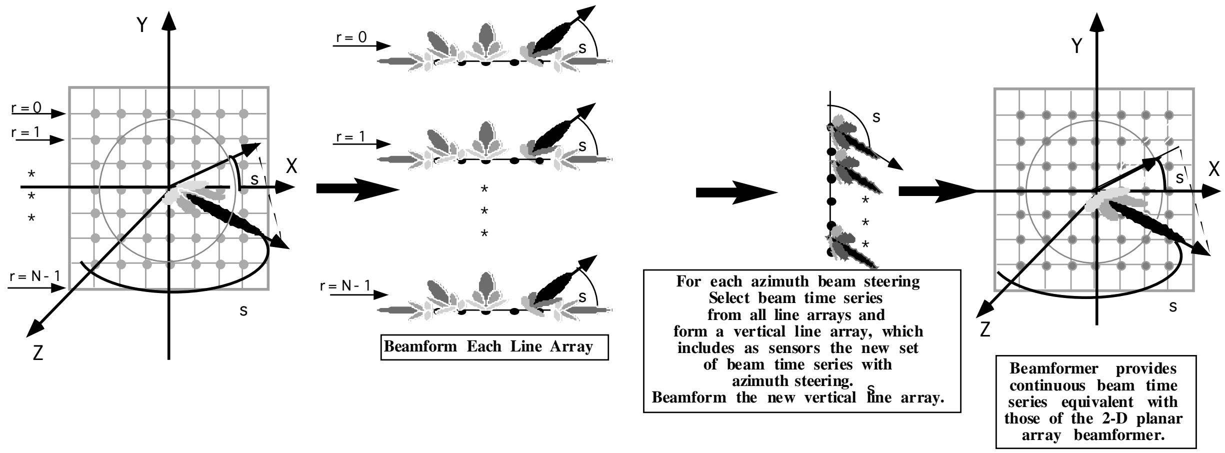
Secondly, all these line array beamformers can be executed in parallel, which allows their implementation in much simpler parallel architectures with commodity PCs, which is a practical requirement for real time system application.



Conventional 3D Beamforming structure for 2d planar array.

3D/4D Visualization Technology

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Telemedicine

A Telemedicine workstation (PC plus telecommunication capabilities) connected with a 4D imaging station (3D-U/S console) with dual use as both a local visualization as well as a telemedicine device, will form part of CANAMET's industrial development activity integrated with the adaptive beamforming and visualization technologies that have been discussed above. The philosophy of the telemedicine tools is to "scan the data, not the patient". In the beginning of a session a 3D-information analogue of a patient is created by a 3D-U/S scan. All subsequent steps are performed on this virtual patient rather than on the real one.

Once the 3D data are replicated on both sides, a co-operative session starts. During this session all events, mouse clicks, commands etc. taking place on one workstation are immediately transferred to the other side. Once there, the workstation of the collaboration partner executes the identical commands, thus creating exactly the same image on the screen. Nevertheless, the only information transferred over the network are the commands initiated on the first place, which require nothing but a few bytes of capacity. Thus, after the latency time of the network (in case of phone lines just a few milliseconds), actions initiated on one side are executed on the other side as well, and both partners see the exactly same image, without transferring any video information. Telecommunications is point-to-point over any TCP/IP network. A telecommunication line can be an Internet connection via a network or a dial-up telephone connection of nay type (modem, ISDN, GSM etc.). Collaborative features include shared viewing, telepointing and control, multi-resolution volume transfer, and graphical synchronization cues. Integrated compression lossy and lossless mechanisms allow significant reduction of the transferred data size. Integrated security, cryptography and authentication mechanisms enable a secure communication under the legal requirements of medical applications.

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[1] S. Stergiopoulos, "Implementation of adaptive and synthetic aperture processing schemes in integrated active-passive sonar systems", Proc. IEEE, 86(2), 358-396, Feb.-98.

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