cSound

A powerful, software-based beamformer image reconstruction platform

Figure 1: Vivid S70 and E90/95; first GE systems built upon the cSound platform

Background

GE's cardiovascular ultrasound imaging team has, since the introduction of the Vivid™ technology platform in 2000, been an innovator in image processing, beam forming and image display. As an example, the Vivid 3 scanner was the first cardiovascular ultrasound system utilizing a PC backend for signal processing and display, combining cost efficiency with innovation for the benefit of our customers.

Since that time, more advanced and increasingly powerful PC based console systems like Vivid S5/S6, Vivid 7 and Vivid E9 and their miniaturized portable siblings, Vivid i and Vivid q, have served the cardiovascular needs of thousands of users and millions of patients, with their proven performance.

Time has now come to take the next leap in image quality performance, quantification and workflow with the introduction of a new generation scanners designed around and built upon GE's new software-based beamformer platform, cSound™.

The Vivid S70, Vivid E90 and Vivid E95 systems all are designed around this cSound platform.

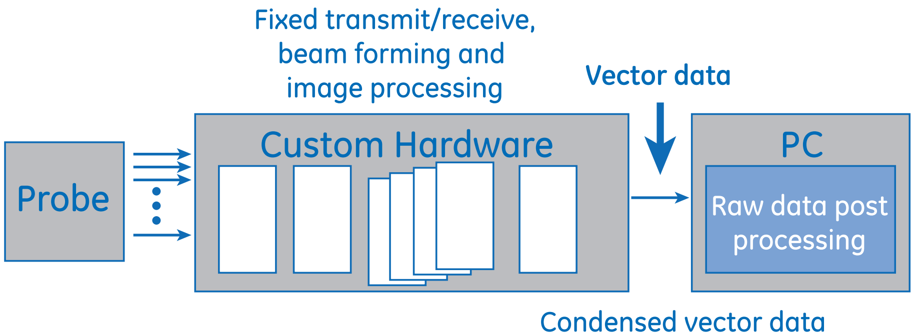

Figure 2: TruScan and Accelerated Volume Architecture

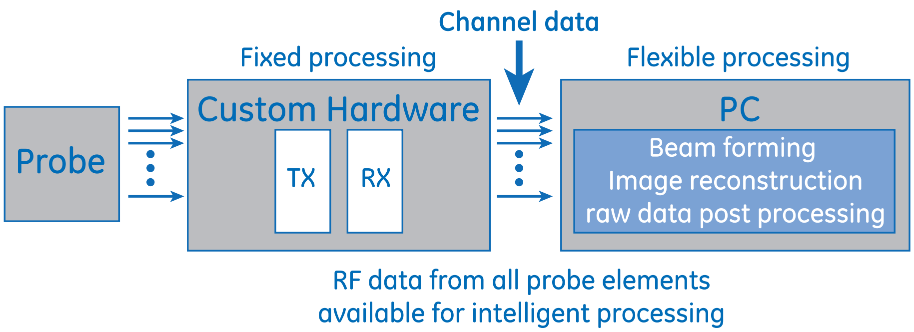

Figure 3: cSound Architecture

cSound architecture

Every patient is different and anyone working in medical ultrasound for some time has experienced this. Even the best ultrasound system may fall short when used on a very difficult to scan patient. The cSound architecture has been designed from ground up to address some of the fundamental limitations of today's ultrasound systems, aiming to make imaging less patient body habitus dependent.

GE's cSound platform introduces a new level of versatility, flexibility and processing power in image acquisition, reconstruction and visualization. The main component in the new platform is a fully configurable software-based image processing chain. The figures below illustrate the TruScan and Accelerated Volume Architecture (Figure 2) used in our prior generation scanners, as well as the cSound architecture (Figure 3) used in our new Vivid S70 and Vivid E90/95 scanners.

Proper preservation of the signals returned from the probe through the system electronics and software processing chain is crucial in order to present diagnostic quality ultrasound images to the users.

The processing chain starts with the shaping of the transmit pulses to obtain excellent axial resolution and penetration with few side lobes to help reduce reverberations, shadowing and other acoustic artifacts. Receive amplification is performed followed by high resolution analog to digital sampling and conversion.

The next step in the processing chain is the beamforming where data received from the probe elements are delayed and coherently summed. In conventional scanners, ultrasound beam forming is implemented with special purpose hardware. Such ultrasound scanners can therefore only support a limited set of fixed and predetermined algorithms, and new algorithms typically require a lengthy hardware redesign. See figure 4 on below left.

In the cSound platform, all beam forming processing is done in our back end processor. This is where RF data from each channel from multiple consecutive and overlapping transmits are received and temporarily stored in the "Local Big Data" channel memory as shown in Figure 4. Then advanced image formation takes place. The algorithms and speed of processing may vary depending on type of console, probe, application and mode. This processing is all software based. The advantages this provides are flexibility and the ability to quickly apply new and innovative algorithms, and also adapts them on the fly to the different modes of operation.

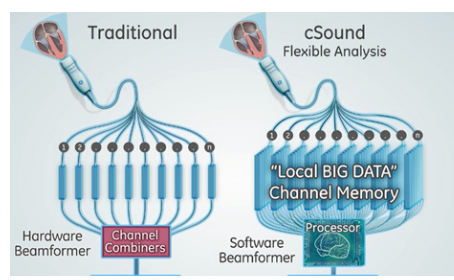

Figure 4: Hardware vs. Software Beamformer

The number of processing channels ("digital channels") is traditionally defined as a number proportional to the channel count that can contribute to the coherent beamsum. In the past, this was constrained by the hardware architecture of the beamformer and its associated processing circuits. Now, with a software beamformer, there is no practical limit to the amount of channel data that may be stored and recombined into a single vector, so the number of processing channels is no longer a relevant technical limitation.

cSound based features and benefits

As mentioned before, the cSound software-based beam forming architecture has opened the door for the development of features and functionality which has the potential to change the way cardiovascular ultrasound is used in the clinic. Below is a selection of some of the features and benefits enabled by this new platform, introduced in this first generation cSound based scanners from GE Healthcare.

True Confocal Imaging (TCI)

So-called "channel processing" where the RF data from each element is kept for further processing, can be used in the beam forming algorithms to achieve enhanced contrast as well as spatial resolution throughout the field of view, in combination with ultrahigh frame/volume rates.

Confocal imaging which previously was implemented by use of multiple focal zones originating from multiple transmits, is now available without loss of framerate and without the line artifacts usually present as a result of multiline acquisition and/or multifocus stitching. The need for a dedicated focus control is made redundant with this technology.

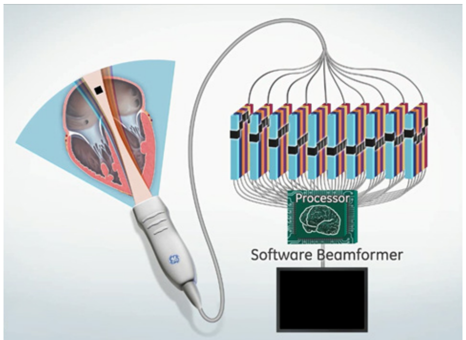

Figure 5: True Confocal Imaging

Key to this feature is the fact that the transmitted ultrasound beams have an hour glass shape which is wide laterally both near and far, and receive data from within these wide transmit beams are collected and stored in the "Local Big Data" channel memory. Multiple consecutive transmit beams overlap in such a way that data for each and every pixel exists in many of the stored data sets in the channel memory. By intelligently processing, the algorithm is able to get an accurate real-time assessment of each pixel value. The end output is, as mentioned, enhanced contrast- and spatial resolution compared to conventional beam forming algorithms.

While this type of imaging without a conventional focal zone control is not unique to GE, our implementation provides flexibility/versatility and easier adaptation to new algorithms than those solutions implemented in hardware/firmware. And since our implementation is based upon commercially available processors, as they develop and are introduced into products, this may then immediately transcend into increased processing power, and ultimately enhanced image quality with the potential of enhanced diagnostic confidence and other benefits that may arise from this.

Adaptive Contrast Enhancement (ACE)

Adaptive Contrast Enhancement is the second feature enabled by the cSound architecture. As for True Confocal Imaging data, any given pixel is first stored into the "Local Big Data" channel memory. Once all data from multiple consecutive transmits are collected and stored in the "Local Big Data" channel memory, the processor accesses this data, and makes two preliminary "internal" images.

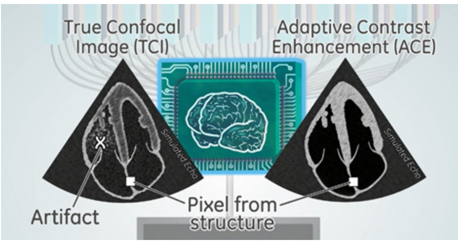

Figure 6: ACE (right) enhancing real structures

In Figure 6, the left image is constructed using the TCI algorithm as described previously. On the right image, the same data is accessed, but with the ACE algorithm the pixel is observed over a short period of time to determine whether or not data for this pixel originated from a "real" structure like in this example from the atrial septum, or not. If the algorithm makes the assessment that the data is real, then it enhances the pixel intensity. If it's noise or artifacts, like in this example inside the right ventricle, the algorithm reduces its intensity. With the high degree of parallel processing available this assessment is done simultaneously for all pixels.

The two internal images are combined to achieve a high contrast resolution image. In Figure 7, compared to the traditional display image on the left, cSound's TCI and ACE combined image on the right has greater clarity with enhanced spatial and contrast resolution throughout the field of view.

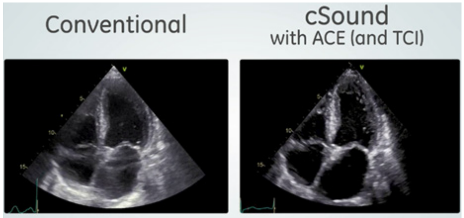

Figure 7: The combined effect of TCI and ACE compared to traditional (Vivid E9) beamforming

The cSound architecture benefits all probes and applications including adult cardiac (2D and 4D, TTE and TEE), pediatric cardiac, fetal/obstetrics, abdominal, pediatric, breasts, thyroid, adult and neonatal cephalic, peripheral vascular, musculoskeletal and urology/prostate.

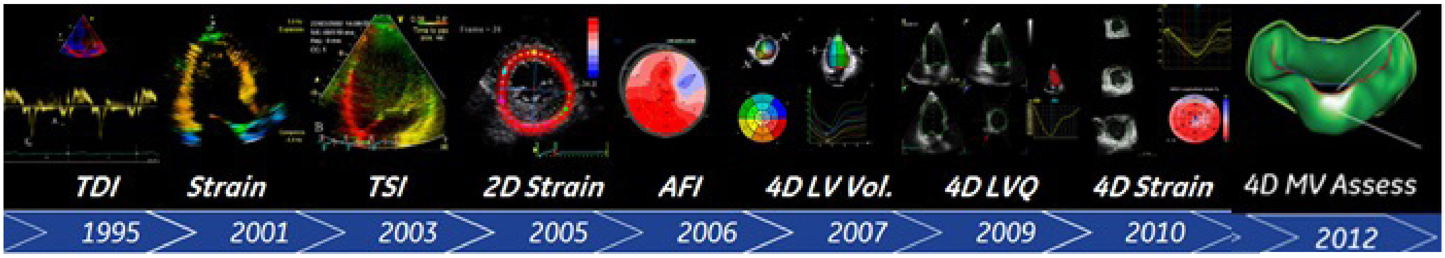

Figure 8: GE Cardiovascular Ultrasound's History of Quantification

Raw data format

Historically the Vingmed scanners and the GE Vivid product line introduction prior to the year 2000, have always acquired and stored its data in a specific raw data format. This has enabled onboard as well as after the fact post processing capabilities which would be otherwise impossible. This flexible and innovative format (storage of pre scan converted data) has enabled development of utilities with high clinical value, like e.g. Anatomical M-Mode - creating an angle corrected M-Mode display from a 2D dataset, and baseline shift in color for PISA measurement done on color loops acquired without baseline shift. The raw data format has also been instrumental in GE's innovations in the area of quantification, from tissue Doppler based techniques in the late nineteen nineties and early two thousands (TVI, Strain, Tissue Tracking, and TSI), via 2D speckle tracking (2D Strain and AFI) to 4D speckle tracking (4D Strain) later introduced on the Vivid E9 platform.

In the progression of platforms (Figure 8) for the above mentioned scanners more and more image acquisition, image processing and display processing were moved from dedicated hardware to software. And over the years this has resulted in an increase in the ability to perform more and more advanced algorithms for all steps in the data processing chain.

It is important to understand that the format of the raw data has not fundamentally changed with the advent of the cSound platform. The huge amount of data in the "Local Big Data" channel memory previously mentioned is discarded after image reconstruction, so the stored raw data file sizes are approximately of the same size as before. A slight increase (20-30%) may however occur, should the user take full advantage of the higher spatial and temporal resolution enabled by cSound.

4D imaging with cSound

Visualization engine

An integral part of the cSound platform is a completely new "visualization engine". The core of this engine is a dedicated software module running on a Graphics Processing Unit (GPU). GPUs are designed for 4D processing in particular, but can also be utilized for 2D graphical operations as well as to offload the CPU in doing computational operations.

The 4D processing chain has been streamlined in order to do fast real-time spatial processing, enabling development and implementation of advanced algorithms like 4D Clarity and HD*live*™ described below (Figure 9).

4D Clarity

Access to channel data in combination with recently developed advanced image processing algorithms has facilitated a new level of image quality, both from a 4D rendering point of view as well as from extracted 2D slice image quality view. The cSound platform enables acquisition of more data than what was the case with our GE predecessors. Development of new intelligent spatial processing algorithms like 4D Clarity provides crisp visualization with excellent resolution/detail level (Figure 10).

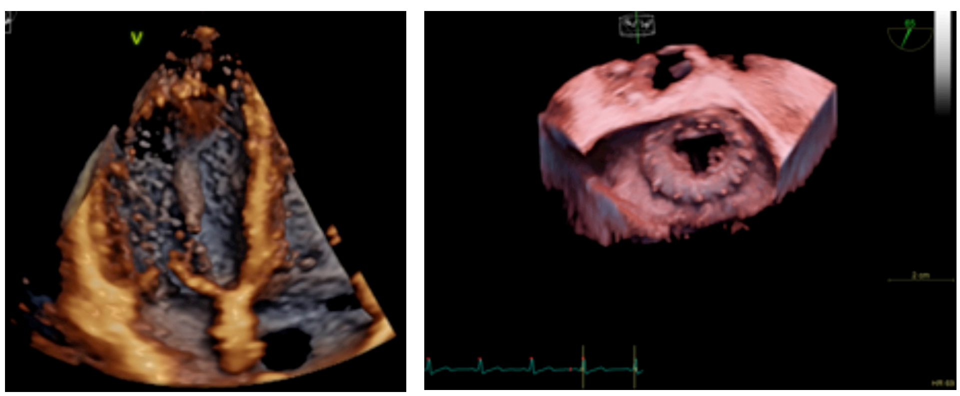

Figure 9: 4D Clarity, HD*live* and cSound acquisition provide excellent TTE and TEE images

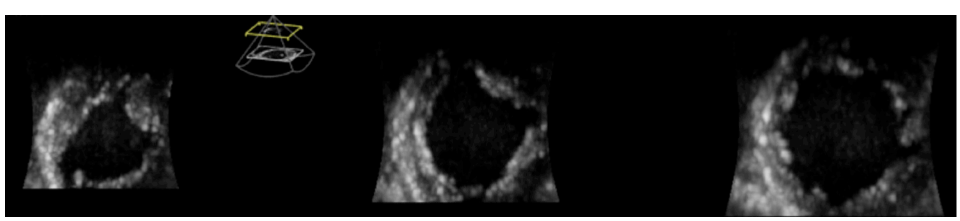

Figure 10: 4D Clarity and cSound acquisition provide excellent extracted slices

HD*live*

The powerful CPU/GPUs required for RF channel data processing also has enabled real-time display of 4D images utilizing an extraordinary rendering method, HD*live*, that generates an amazingly realistic visualization of the human heart, through advanced illumination, shadowing and reflection algorithms. HD*live* can be used to enhance 4D depth perception during image-guided interventions or in the echo lab for "normal" TEE or TTE imaging. The technology behind this feature is extremely resource demanding, and is enabled by the cSound platform and its powerful processing capabilities, whether during high volume rate single- or multi-beat 4D imaging.

Basically, HD*live* is a real-time simulation of light travelling through tissue giving the user a realistic perception of the shape of valves and other clinically important structures (Figure 11) where a catheter is visualized and illuminated by a light source located at approximately 2 o'clock, casting a shadow on the wall behind it. Also notice how the surfaces reflect light, and in combination with the light scattering through tissue, create a three-dimensional perception even when shown in the two dimensional picture (Figure 11).

Figure 11: HDlive visualizing a catheter during an interventional procedure

Algorithm overview

The HDlive algorithm contains several sub-features that are described below. By following the sub-chapters and images one can see how the image is constructed step-by-step.

Depth coloring

Depth coloring is well known from the past and frequently used for rendering volumes in cardiac applications (both with TTE and TEE probes). Depth coloring enhances depth perception but does not give a lot of detail. Depth coloring has, however, previously not been integrated with diffuse volume shadowing. (Figure 12)

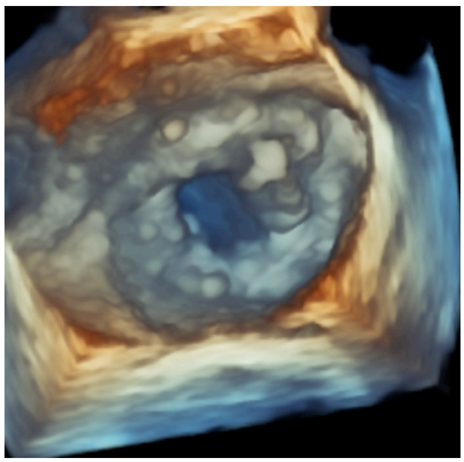

Figure 12: Depth coloring by itself provides limited detail

Direct lighting

Direct lighting is applied to the scene in order to create sharp shadows via monochromatic light attenuation. These shadows help with perception of small details in the image. The image may however become quite dark in several regions if the light attenuation is very strong. (Figure 13)

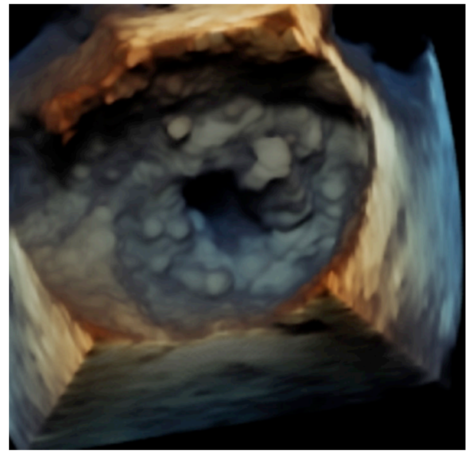

Figure 13: Direct lighting adds shadows, but certain regions can become dark

Indirect lighting

Indirect lighting is applied to create soft shadows via diffuse chromatic light attenuation. This part of the algorithm simulates light scattering effects creating soft-colored shadows. In the example shown below, light attenuation for the blue color is lower than the other colors, which means that the diffuse shadows will be bluish. (Figure 14)

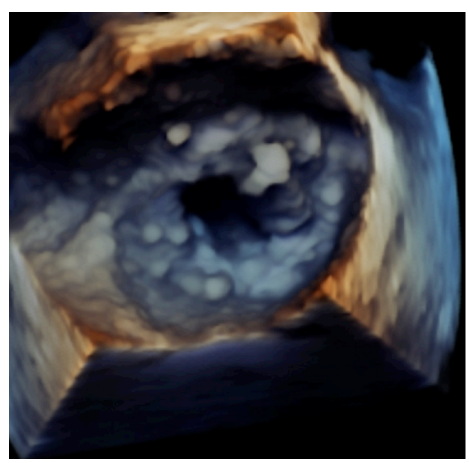

Figure 14: Indirect lighting creates soft shadows

Ambient lighting

Ambient light is added to the scene to lighten up the dark parts of the image. In Figure 15, one can see a combination of direct, indirect and ambient lighting.

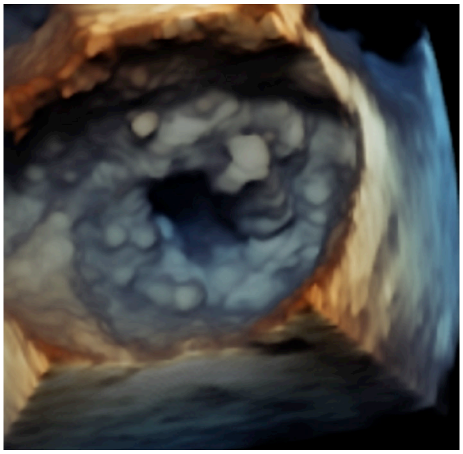

Figure 15: Ambient lighting adds light to the dark regions

Specular and diffuse reflections

Specular and diffuse reflections are added to brighten up details. These are simulating light reflections from the light source hitting the surfaces and bouncing back towards the eye. They are both depending on the light direction, the local surface orientation (normal) as well as the viewing direction. Shown in Figure 16 are added specular reflections as well as a bit of diffuse reflections to the previous rendering.

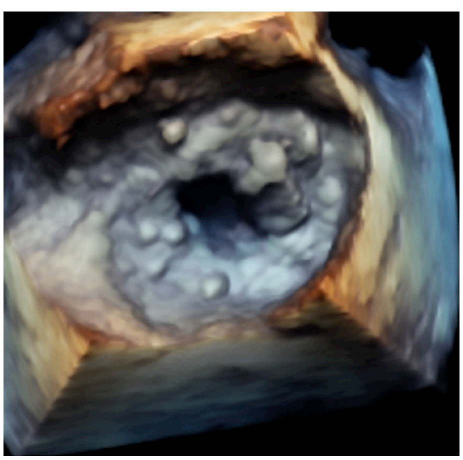

Figure 16: Specular and diffuse reflections brighten up details

HDR processing

Similar to what is implemented in state-of-the art cameras, HDR (High Dynamic Range) processing is added to the image. Basically this step greatly enhances local contrast in shadow regions visually extending the dynamic range of the rendered image. (Figure 17)

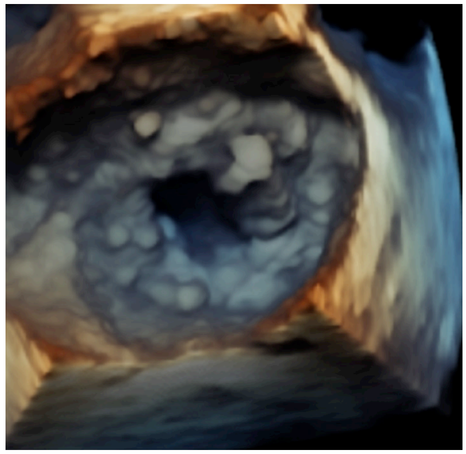

Figure 17: HDR greatly enhances local contrast

Moving the light source

By moving the light source (easily controlled by a rotary) the shadows and reflections are adjusted interactively. Shown in Figure 18 what happens when the light source is rotated so that the light comes from above (left image) and below (right image)

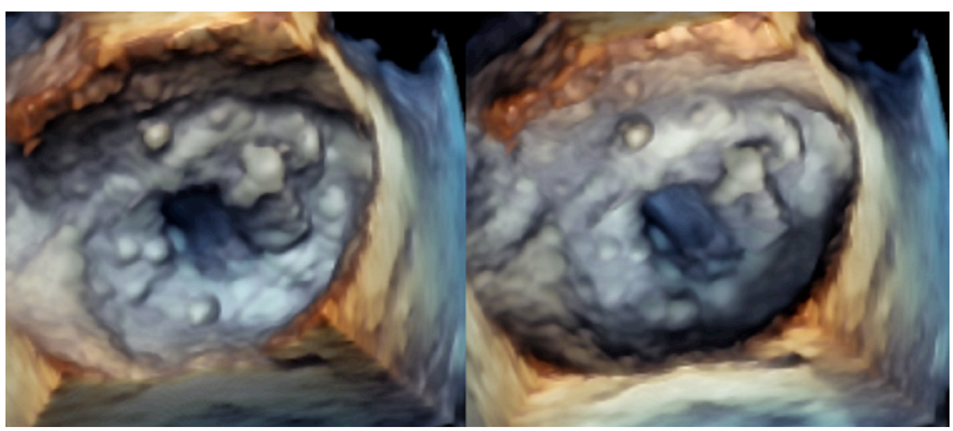

Figure 18: Moving of the light source may enhance certain details

Summary

In many ways, the new cSound platform is taking our raw data to the next level. It does this by providing a magnitude more information upfront for real-time processing compared to what is available in the previous platform. As computer technology evolves, so will the processing power of the cSound platform and its imaging capabilities.

In this first generation cSound based systems we have focused on

- developing new leadership scanners with 2D (Vivid E90/95) and 4D image (Vivid E95) quality and quantification tools that may enable the user to reduce the number of sub-optimal exams with enhanced diagnostic confidence
- developing a new level of high end scanners (Vivid S70) with the performance of current GE leadership systems, and further enhancing the ease of use and portability of its predecessor

What the future will show is unknown, but as you collaborate with GE on the cSound path be assured that you are on a fast moving track always striving towards better and better patient care.

About GE Healthcare

GE Healthcare provides transformational medical technologies and services to meet the demand for increased access, enhanced quality and more affordable healthcare around the world. GE (NYSE: GE) works on things that matter - great people and technologies taking on tough challenges. From medical imaging, software & IT, patient monitoring and diagnostics to drug discovery, biopharmaceutical manufacturing technologies and performance improvement solutions, GE Healthcare helps medical professionals deliver great healthcare to their patients.

Imagination at work

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