Trends w. Ultrasound Scanners
Clinical and Research Implications

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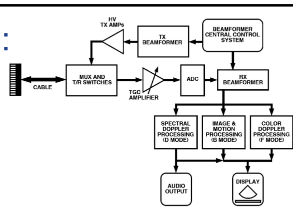
imagination at work

What are the trends affecting ultrasound scanners?

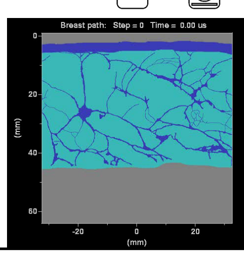
How are scanners and their use changing?

- Miniaturization
  - More dense beamformation ASICS and increased use of front end ASICs
  - Migration of electronics and beamformation to probe handles
  - Continued migration of functionality to software
  - New applications enabled by low size & low cost
- Increased use of 3D/4D Imaging
  - Mechanical 1D arrays
  - 2D arrays w. electronic 3D beam steering and focusing
- Software beamformation
  - Potentially dramatic changes in scanners and their application

Ultrasonic Imaging: A Quick Intro



- Pulse echo mechanism
- Echoes generated by variations in density & compressibility of tissue.
- Commonly one acoustic ray's worth of data acquired at a time.
- Data from such a ray rebinned to create a raster image.



Block Diagram courtesy of Analog Devices
Video clip courtesy of Dr. R. Waag, U. of Rocheste

Ultrasonic Imaging – Setting the stage

Some Scanner History

- Beamformers introduced w. array-based probes in late 1970s.
- Analog beamformers
  - Late 1970s to 1990s
- Digital beamformers
  - 90s
- Hybrid analog/digital beamformers
  - 2000s
- Software beamformers
  - 2000s and on-going

Ultrasound "re-invents" itself every few years.
We seem to be heading for such an event right now …

Ultrasound Migration

… and the day after.

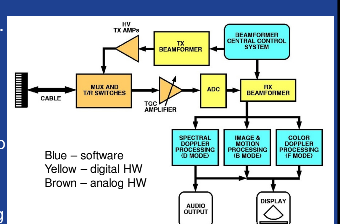
Today

Also today

Trend toward scanner/beamformer miniaturization

Miniaturization

- Trend is well on its way and may be accelerating.
  - Increasing number of laptop systems
  - Two vendors have handheld systems
- Major enablers
  - Migration of functionality to software
  - Migration of beamformation to handle.
  - Reduced size of remaining ASICs

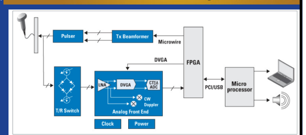


We need to start thinking of a scanner as being iPad-sized and smaller.

Another interesting source of excitement …

Role of Semiconductor Companies

- Traditional Role:
  - Suppliers of specialized ICs
    - TGC amplifiers
    - A/D converters
    - Multiplexing
- Emerging Role:
  - Front end subsystem suppliers
    - Chip sets from pulsers to A/Ds
  - Computing engines for beamformation, image formation and processing
  - MEMS transduction (e.g. cMUTs)???
- Potential Impact:
  - Significantly reduced hardware role for traditional scanner suppliers (e.g. GE)
  - Will the differentiation among the suppliers be based on software?
  - Very nice benefit for academic researchers



Now incorporated into the TI product line

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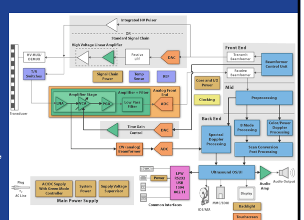


TI offers products for each colored block in the diagram.

Possible Scenario for Scanner Future

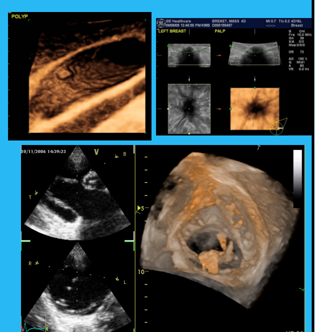
- Scanners will consist of an array, front end, and a processor.
- How small can we go?
  - Depends largely on how small processors can get.
- What about Moore's Law?
  - It is, unfortunately, is not doing so well.
- How miniaturized can multi-core engines, GPUs get?
  - TBD
- Hybrid designs likely in the near future …

Let’s look at other trends involving ultrasound …

Trend towards 3D/4D imaging

3D/4D Imaging

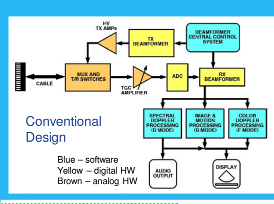
- Increasingly common in ob-gyn and cardiac applications
  - Implementation of mechanical 3D/4D less complex – modest system impact
  - Electronic 3D/4D requires major probe redesign
    - Split beamformation to digital & analog parts.
    - Migration of electronics to probe handle.
- Several clear roles for 3D/4D imaging in cardiology, e.g.
  - Surgical planning
  - Stress echo
  - More exact volume and ejection fraction estimation

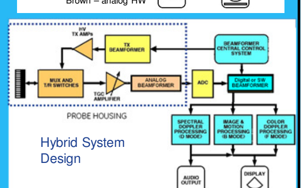


Migration of beamformation

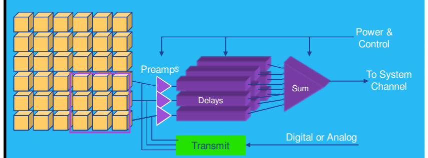
Spatial sampling for 3D/4D imaging

- Cardiac 3D/4D probes have 2,500 + elements, general imaging needs much more than that.
  - This large number necessitates migration of part of the beamformer to the probe handle.
  - Contact area of abdominal probes much larger than cardiac, hence greater complexity.
  - Same is true for high frequency vascular/small parts probes





Migration of Beamformer to Probe handle.



- Connects a group of transducer elements to each system channel
- Low-power analog beamformer: Phase rotation or Delay lines
- Small delays only: static steering of small sub-aperture
- Dynamic focusing & full-aperture delays by system beamformer

One basis for miniaturized systems

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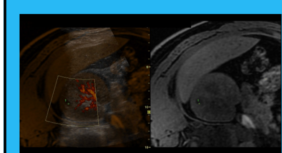
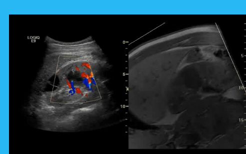
Thomenius, PhD, AAPM 2012
8/2/2012

Another trend – fusion of ultrasound w. other modalities

- Using electromagnetic position sensors and manual registration, one can associate real-time ultrasound w. a stored 3D CT or MRI data set.
- This permits a unique fusion of the features of the two modalities.



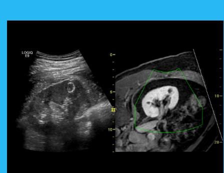
US/MRI Pediatric Kidney



US/CT kidney Comparison

Another trend – fusion of ultrasound w. other modalities

- Another fusion opportunity comes from diagnosis of lesions with the mutual information.
- The images below permit clearer identification of the nature of the lesion than would be possible otherwise.



US/CT Renal Mass side by side

Side-by-side Fusion MRI/US
Elastography shows a soft lesion BI-RADS 3. Fibroadenoma.

Now, a really big trend …

Towards software beamformation

Major challenges:

- Data transfer from front end to computing engine
  - Several GB/sec required

Choices on computing engines:

- General purpose PCs
- GPUs
- DSPs

All are viable.

Benefits:

- Scanners become more independent of hardware development cycle.
- Novel beamformation concepts become feasible.
  - Direct processing of channel data, e.g. SLSC.
  - Expand beyond basic delay-and-sum beamformation.
  - Plethora of new algorithms that can now be realized in real-time.

We are heading for scanners composed of an array, analog front end, and a processor.

Clinical benefits from software beamformation

Clinical benefits:

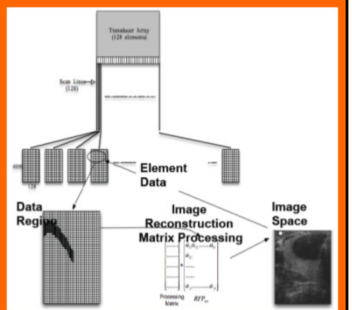
- All benefits from real-time implementation of novel beamformation algorithms.
  - In many cases, benefits yet to be demonstrated in clinic since SW beamformation needed for such demonstration.
  - This should be just a matter of time.
- Far easier integration of aberration correction than with hardware.
  - Applies to all processing involving individual element data.
- Availability of channel by channel RF data sets will accelerate pace of research into image reconstruction.

Increased similarity to reconstruction-based imaging

Software Beamformation: One Concept

Specific Example:

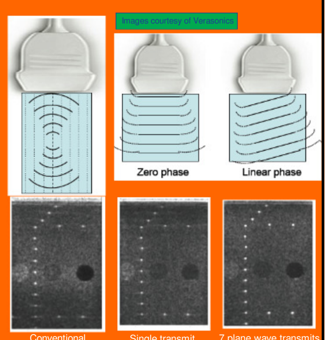
- Verasonics design
  - Image constructed one pixel at a time.
  - A major departure from conventional delay-sum which forces ray path reconstructions
  - Process reduced to matrix multiplications.
  - Data from multiple transmits can be applied



Software Beamformation: One Concept

Data acquisition scheme:

- Conventional method
  - Fixed focus
  - Single ray acquisition
- New scheme
  - Transmit broad plane wave
  - Store data from all elements

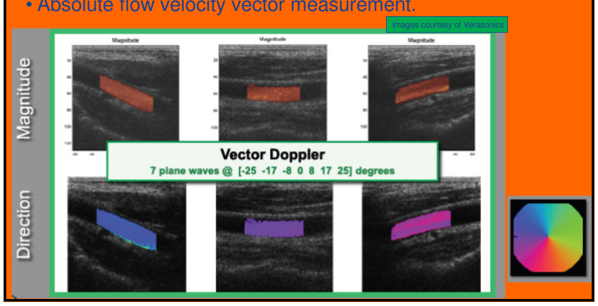


Beamformation is now more like reconstruction.

Additional benefits from SW beamformation

Specific Example:

- Absolute flow velocity vector measurement.



Some possibilities arising from SW Beamformation

- Multi-transmit schemes enabling dynamic focusing on both transmit and receive.
- Aberration Correction – adjustment of beamformation parameters to correct for speed of sound variation
- Real-time data dependent modification of beamformation algorithms.
  - Short lag spatial coherence (SLSC)
  - Complex dynamic apodization functions, e.g. Minimum Variance Beamformer

Now, where does all of this take us in the clinic?

imagination at work

Clinical Implications of miniaturization, software based scanners

Clinical Impact

- Spread ultrasound throughout the hospital.
  - Far more specialized scanners
  - Point-of-care rapid diagnostics
  - Procedure guidance
- Spread outside the hospital
  - Small clinics
  - PCPs
  - Rural health care
- Not clear where the process will end
  - Death of the console?

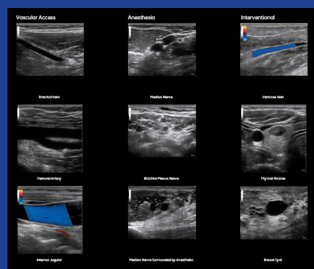
Technical challenges changing from beamformer design to system automation.

- New sets of users with less direct and continuous ultrasound experience.

Numerous reimbursement & regulatory implications …

Emerging clinical applications for miniaturized systems

Clinical areas
- Anesthesia
- Interventional
- Emergency Department
- Point of care applications
- Primary care
- Rheumatology
- Rural health care
- Sports medicine
- Vascular access

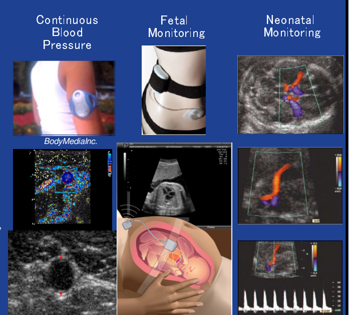


All examples of migration from traditional utilization sites

Ultrasound in Patient Monitoring?

We have looked at the possibility of ultrasound-based patient monitoring.

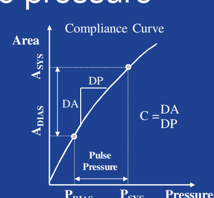
Some needs:
- Automatic searches for clinical targets
- Continously & automatically measure desired parameters
- Report results on a continuing basis



Relating arterial area to pressure

The relation is nonlinear and varies with age and degree of nervous stimulation.
- Number of approximations exist.
- Re-calibrations w. cuff measurement may be required.

Mathematical models
- Several models have been developed.
- Age-related stiffening can be included in these.



$$p(t) = p_d \, e^{\alpha\left(\frac{A(t)}{A_d} - 1\right)},$$

$$\alpha = \frac{A_d \ln(p_s/p_d)}{A_s - A_d}.$$

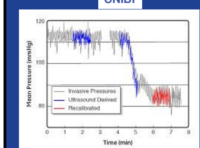
From Meinders & Hoeks: UMB vol. 30: 147 - 154

Several significant challenges remain ...

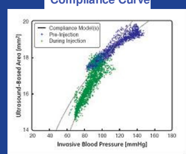
Compliance variation with vasodilator

- Under NIH funding we are investigating the role of nervous control system and compliance.
- With introduction of a vasodilator, we see a dramatic drop in the mean arterial pressure
  - Light blue – catheter based blood pressure measurement
  - Dark blue – ultrasound measured diameter estimate w. an assumed compliance
- The vasodilator introduced a significant shift in the curve (blue to green).
- We defined a “hemodynamic state” descriptor which appears stable in the pre- and post-injection periods.

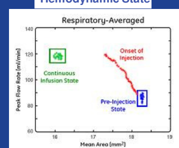
CNIBP



Compliance Curve



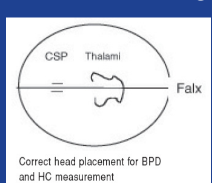
Hemodynamic State



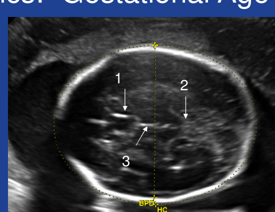
Continuous blood pressure estimation

- There are clearly numerous sources for compliance modulation.
- This will take a good amount of investigation to tease out all the factors.
- Key issue is the accuracy needed for continuous blood pressure monitoring.
  - The gold standard, cuff based oscillometry, is not very good.

Automated Diagnostics: Gestational Age



(http://www.fpnotebook.com/ob/rad/ftlbprtldmtr.htm)



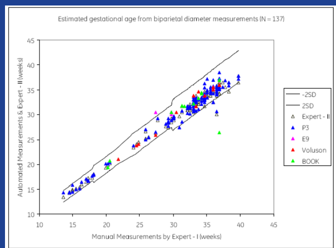
➢**Orientation**
Perpendicular bisector of falx line

1 – Cavum Septum Pellucidum
2 - Thalami
3 – Falx line / 3rd Ventricle

➢**End points**
Measured from the beginning of the fetal skull to the inside aspect of the distal fetal skull (outer to inner)

Automated Measurements

Validation on 137 images



GA predictions from BPD measurements using Hadlock tables [1] are within 1SD on 95% cases and 2SD within 98% cases when compared to expert measures.

Implications of these trends to researchers

Ultrasound as a tool for biomedical investigations

- Supplies input to physiological modeling programs
  - Blood flow data to hemodynamic modeling
  - Organ dimensions to patient specific modeling, serial studies
  - Simulation driven acquisition
- Novel data acquisition schemes
  - Data driven intelligent acquisition: achievement of greater clinical certainty
- Automated 3-space searches for organs, contrast agents, lesions, response to drugs, etc.
- Automated assessment of therapy impact

Summary

- Several transformative ultrasound trends reviewed.
  - Major changes to practice of medical ultrasound highly likely.
  - Migration from Radiology & Cardiology is happening.
- Software beamformation may yet have the most impact of the trends discussed.
  - Ultrasound scanner: transducer, front end, processor.
  - Scanner as a tool for patient monitoring, physiological data acquisition, and system analysis.

Thank You!

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