Fortschritte in der Ultraschallbildgebung

Karsten Hiltawsky

GE - Global Research Europe Imaging Technologies

Garching b. München
Outline

Where do we come from?
Where are we right now?
Where is need for improvement?
Where is room for improvement?
Where are potential applications?
Who will drive innovation?
1D Ultrasound (Imaging)

Single Element Transducer (PZT)
Single Channel Electronic
1D → 2D Ultrasound Imaging

1977: Kretz Technik Combison 100
Rotating Single Element Transducer
Single Channel Electronic
1D → 2D Ultrasound Imaging

Late 70’s, early 80’s until today:
PZT-Matrix Array with subaperture
Multichannel Electronic
1D → 2D Ultrasound Imaging

Late 70’s, early 80’s until today:
Optimization of PZT matrix arrays, multichannel electronics and beamforming
1D → 2D → 3D Volume Ultrasound

90’s until today:
Rotating PZT matrix array with subaperture and multichannel electronics
1D → 2D → 3D → 4D

mid 90’s until today:
2D PZT matrix array with subaperture and multichannel electronics
1D → 2D → 3D → 4D

How come?
Block Diagram of an ultrasound system
Block Diagram of an ultrasound system

- D/A
- A/D
- Tx Beamformer
- Rx Beamformer
- Beamformer Control Unit
- Image (B Mode)
- Spectral Doppler
- Color Doppler
Block Diagram of an ultrasound system

1. MUX & T/R switches
2. TGC
3. AMP
4. D/A
5. Tx Beam-former
6. Rx Beam-former
7. Beamformer Control Unit
8. Image (B Mode)
9. Spectral Doppler
10. Color Doppler

FRONT END

BACK END
Migration of HW Functionality to SW

• Conversion of HW functionality to software since ’95:
  • PC-based back end
    • Scan conversion
    • Doppler processing
    • Image processing including 3D/4D rendering

• Can more functions migrate to SW?
  • Beamformation migration more challenging
  • Two start-ups have offered products w. SW beamformation
Beamformation Miniaturization: Digital ASICs

- Digital ASICs (yellow blocks)
  - Continuous improvements in ASIC density
  - Major impact: channels per chip
- Driven by intense competition in semiconductor industry.
- Line between SW and HW getting fuzzier.
  - DSP beamformation w. stored beam data.
- Two trends: increased channel density & migration to SW
Analog Components

- Analog ASIC development
  - Slower development than with digital ICs
  - Most noise sensitive areas of a scanner
  - Most driven by ultrasound industry
  - Still, much progress being gained:
    - Octal DACs, octal and quad pre-amps and pulsers
    - Migration of beamformation & analog functions to probe handle (e.g. RT3D)
Status & Trends

✓ Nearly fully-featured handheld systems are available.

• Design issues:
  > Level of compromise in performance required
    – Channel count reduction
    – Coarser sampling
    – Folded architectures

• Clinical utility realized
  > Portability is good but is the diagnosis?

Long term trends: Analog electronics to probe, Digital electronics to SW, Moore’s Law everywhere.
What will drive further “advances in ultrasound imaging”?

**Technically**
- Advances in image quality due to different technology breakthroughs
- More information due to additional parameters
- Geometry of probes can become application specific
- Ultrasound benefits from advances in electronics

**Clinically**
- Improvement of image quality
- Disciplines (general imaging, gyn-ob, cardiology)
- New applications
- Impact on workflow
- Improved documentation features
1D → 2D → 3D → 4D → ???

What is next?
1D → 2D → 3D → 4D → ???

✓ Volume ultrasound

✓ Miniaturization ("visual stethoscope" of the future)

Probes!
Transducer Array Taxonomy

- **Aperture**
  - Fixed
  - Discrete
  - Dynamic
  - Dynamic
  - Dynamic

- **Focus**
  - Static
  - Static
  - Dynamic, Symmetric
  - Dynamic, No Symmetry Constraint
  - Dynamic, Steerable

- **Elevation**
  - 1D
  - 1.25D
  - 1.5D
  - 1.75D
  - 2D
Rationale for Elevation Beamformation

Limited performance available with 1D designs
> Poor beamformation away from elevation focus.
> Limits on size of elevation aperture due to fixed focus.

Slice thickness improvement throughout image
> Expanding aperture, dynamic focusing in elevation
Single- vs. Multi-Row Arrays

Phantom with 2 mm Spherical Cysts
cMUT: Reconfigurable Array Concept

Cells are hardwired together to form larger acoustic subelements. Thousands of subelements are connected or disconnected to each other and to system channels via an underlying switch matrix.

cMUTs are ideal for easy integration to electronics since they are manufactured using semiconductor materials and processes.

Electronically controlled apertures, scanning, and steering
1D → 2D → 3D → 4D → ???

Volume ultrasound

Miniaturization (visual stethoscope of the future)

Probes (cMUT, pMUT)

Image Quality

Adaptive Beamforming!
Sound propagation in water

We assume that

\[ c_{\text{tissue}} = 1540 \text{ m/s} \]
during transmit beamforming!

Concept of a schlieren system (Toepler, 1894)
Sound propagation in breast tissue

How does it look like in biological tissue?

Courtesy of R. Waag, University of Rochester
Sound propagation at chest wall

We can correct for the wrong assumption of $c_{\text{tissue}} = 1540 \text{ m/s}$ during receive beamforming!

Courtesy of R. Waag, University of Rochester
Beamforming With Aberration

Point-like scatterer

Spherical wavefronts

Aberrating Layer, $c \neq c_0$

Transducer

Geometric beamforming delays

Channel data poorly aligned
In-Vivo Time Delay Correction

Pancreas and Superior Mesenteric Artery

SMA 4.4 dB darker, pancreas 1.4 dB brighter
1D → 2D → 3D → 4D → ???

Volume ultrasound

Miniaturization (visual stethoscope of the future)

Probes (cMUT, pMUT)

Image Quality
- Adaptive Beamforming
- Coded Excitation!
Coded Excitation

Transmitted Pulse Train

Received Pulse Train

Encoder

Decoder

Body

Coded Excitation improves sensitivity without resolution tradeoff
Coded Excitation - Experiment

High Frequency

Coded Excitation

Improve penetration by 3 cm with same resolution to -50 dB
1D → 2D → 3D → 4D → ???

Volume ultrasound

Miniaturization (visual stethoscope of the future)

Probes (cMUT, pMUT)

Image Quality:
- Adaptive Beamforming
- Coded Excitation

Parametric imaging!
Elasticity Imaging

Many approaches for imaging mechanical properties are available!
1D → 2D → 3D → 4D → 4D+

**Volume ultrasound**

**Miniaturization** (visual stethoscope of the future)

**Probes** (cMUT, pMUT)

**Image Quality**
- Adaptive Beamforming
- Harmonic Imaging, Coded Excitation
- Contrast Agent Imaging (targeted)
- Parametric Imaging (elasticity, metabolic information)
1D → 2D → 3D → 4D → 4D+

Volume ultrasound

Miniaturization (visual stethoscope of the future)

Probes (cMUT, pMUT)

Image Quality
- Adaptive Beamforming
- Harmonic Imaging, Coded Excitation
- Contrast Agent Imaging (targeted)
- Parametric Imaging (elasticity, metabolic information)

Workflow
- e.g. Image Fusion, Navigation, Documentation

Therapy (targeted drug delivery, HIFU)
Thank you.