Medical diagnostic systems

(Orvosbiológiai képalkotó rendszerek)

Emerging ultrasound applications

(Fejlődő ultrahang alkalmazások)

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What is driving innovation in diagnostic ultrasound?

- Advances in array technology
  - birth of ultrasonic imaging brought about by discovery of piezoelectricity
  - what about current advances in micromachining and circuit printing?
- Advances in high-speed electronics and computing
  - what algorithms can we run on data in real time?
  - can we also adaptively control the transmit sequence in real time?
- Theoretical and computational models
  - where do we get new ideas from?
- Emergence of new imaging modalities
  - we fuse images of various modalities...can we fuse the modalities themselves?
  - can we adapt to the needs of new therapies, e.g. HIFU?
- Practical, economic and social considerations
- Overall trends

Advances in array technology

- Invasive ultrasound devices (endoluminal US) such as catheter-based intravascular US have been around for some time and are indicative of the minituarisation possible with ultrasound transducers
- 2-D arrays: finally we have the required quality and spatial density. Advantage over scanned 1-D scanned array 3-D US: high frame rate, transverse planar imaging
- Micromachined ultrasound transducers (MUTs) [Zhou *et al.* 2010], including capacitative (CMUT) transducers [Eames *et al.* 2009]: cheap, high-frequency transducers. CMUTs have high sensitivity (though not necessarily high output).
- Flexible transducers [Culjat *et al.* 2009] promise wearable sensors that surround the body for ultrasound tomography
- High-frequency transducers (>10MHz) allow high-resolution images to be generated
- Acoustic microscopy (>50 MHz) has shown tissue microstructure. At >400 MHz, it can even show cells [Lemor *et al.* 2004; Weiss *et al.* 2007]. This informs scattering models of tissue that are still being actively developed [Doyle *et al.* 2009].

Advances in high-speed electronics and computing

- Digitisers, digital signal processors (DSPs), memory are becoming cheaper
- Receive beamforming can now be done in the digital domain and several beams can be formed from one transmission [Mo *et al.* 2008].
- Since the image algorithm is digitally implemented, the ultrasound imaging system becomes a platform for testing new algorithms [Tortoli *et al.* 2009].

<u>Processors are not only becoming faster: new architectures are being used</u>

- MIMO nature of image reconstruction makes parallel computing a natural option
- Graphical processing units (GPUs) are becoming easier to program and are indeed used in an ultrasound tomography device [Garland *et al.* 2008]
- Other architectures, e.g. cell broadband engine are also viable solutions in medical imaging [Harris 2007]
- The transition from single-core to many-core computing means that it is not enough to optimise algorithms around an architecture: ideally, novel algorithms should be designed that exploit the inherent computing structure [Roska] (e.g. data flow graph)

Theoretical and computational models

- For several decades, theoretical developments could not be quickly or affordably implemented and remained firmly in the laboratory (e.g. diffraction tomography)
- Now, arguably, theory is lagging behind the available technology
- Many advanced imaging techniques (synthetic aperture, coded excitation, adaptive imaging), though available to the radar and sonar community for many years, are still largely in the experimental stage for ultrasound
- With more data being collected on the viscoelastic and scattering properties of tissue, as well as the effect of disease properties on these parameters (see, e.g. [Vlad *et al.* 2010]), quantitative ultrasound (QUS) will hopefully be developed to the point that it can give high-resolution images directly comparable with known parameter distributions for healthy/diseased tissue
- Fast and accurate simultaneous models such as DELFI [Ellis *et al.* 2007] that complement the widely-used Field II help the development of better imaging algorithms [Ellis *et al.* 2010], as do the availability of customizable imaging platforms mentioned in the previous slide

Emergence of new imaging modalities

- Different modalities vary in the physical properties they measure and their technical (penetration depth, resolution) advantages
- Combining two modalities hopefully means "taking the best of both worlds"

What possible combinations are there with ultrasound?

- Acoustooptics [Bossy *et al.* 2005] Mean free path of tissue ~0.1 mm. Beyond several millimetres, light is diffuse. However, optical contrast is achieved at higher depths by scanning the tissue with ultrasound and observing changes in the diffuse light using an optical interferometer.
- [Opto,photo,thermo]-acoustics [Laufer *et al.* 2010] An acoustic shock wave is generated by thermal absorption of electromagnetic radiation, e.g. laser light. The time of flight to the receivers gives spatial information. Again, optical contrast is provided at depths not possible using conventional optics.

Emergence of new modalities

- New modalities may involve only acoustics, however often the physics transcends classical linear scattering...
- (Visco)elastography, e.g. vibroacoustography [Alizad *et al*. 2008] often involves shear waves
- Harmonic imaging is an established ultrasound modality involving the harmonics of the transmitted ultrasound wave
- However, imaging the subharmonic [Forsberg *et al.* 2000] and broadband inertial [Gyöngy and Coussios 2010] responses of bubbles is relatively recent (although latter method maps bubbles that are made to cavitate for therapeutic purposes and is therefore not a diagnostic imaging modality)
- Many of these modalities are being developed to help monitor therapies such as high intensity focused ultrasond (HIFU) and ultrasound-induced drug delivery

Practical, economic and social considerations

- What turns a continually "emerging" solution into one that is actually adopted?
- Four ways a solution/invention will be adopted by a company:
  1. Make it freely available on academic journals. If details are missing companies may be reluctant to adopt it (lack know-how, paper may be glossing over difficulties), or they need a new twist to be able to patent it and acquire exclusive rights.
  2. Patent, license to existing companies. Companies need to be convinced by papers/demos.
  3. Start-up: will need extensive experience of working in a relevant company.
  4. Develop it in-house as an employee of the company.
- Seemingly attractive solution will fail if not marketed well!
- Not only companies, but doctors and patients will also need to be convinced
- The solution should be cost-effective and easy to integrate into existing hardware (*cf.* DRX technology for X-rays [Gémes 2010])

Innovation vs invention [Larry Mo, personal communication]

- Apple did not invent MP3 player, but iPod outstanding innovation
- Companies do not mind that they cannot invent everything: they are happy to creative an innovative product out of an invention whose
  - license they may need to pay
  - to which they may not be able gain exclusive rights
- Companies are keen to form partnerships with academia
  - joint governmental grants
  - research group receives modified, “research system” on which to develop invention
  - company has early access to technology/discovery
  - company is better able to assess system requirements, costs and business impact: this helps make an innovation out of an invention

Overall trends [Larry Mo, personal communication]

- image reconstruction becoming more software-based
- systems more compact and ubiquitous due to electronic miniaturization
- rapid growth in "point-of-care applications": scanner brought to the patient rather than patient being transported to the Imaging Department of the hospital

Some notable diagnostic ultrasound research groups

Basic Radiol Sci Ultrasound Group, Univ Michigan, http://www.ultrasound.med.umich.edu/

Bioacoustics Research Lab, Univ Illinois, http://www.brl.uiuc.edu/

Center for Fast Ultrasound Imaging, Tech Univ Denmark, http://www.dtu.dk/centre/cfu

Microelectron Syst Design Lab, Univ Firenze, http://www.unifi.it/msdlab/

Photoacoustic Imaging Group, UCL, http://www.medphys.ucl.ac.uk/research/mle/

Resource Center for Med Ultrason Transducer Tech, Univ Southern California, http://bme.usc.edu/UTRC/

Ultrason and Elastographics Lab, Univ Texas, http://www.elastography.com

Ultrasound and Elasticity Imaging Laboratory, Columbia Univ, http://www.bme.columbia.edu/eekweb/

Ultrasound and Optical Imaging Team, Inst Cancer Research, http://www.icr.ac.uk/research/research_sections/physics/teams/ultrasound_and_optical_imaging_/

Ultrasound Laboratory, Univ Wisconsin, http://www.ultrasound.medphysics.wisc.edu/

NB: *The list is not exhaustive! Groups investigating image formation/reconstruction have been favoured over those investigating image processing/analysis.*

Some notable diagnostic ultrasound companies

Aloka, http://www.aloka.com/

B-K Medical, http://www.bkmed.com/

GE Healthcare, http://www.gehealthcare.com/euen/ultrasound/

Hitachi Medical Systems, http://www.hitachi-medical-systems.co.uk/products-and-services/ultrasound.html

Medison, http://www.medison.com/

Philips, http://www.healthcare.philips.com/in/products/ultrasound/

Siemens, www.siemensultrasound.com/

Sonomed, http://www.sonomedinc.com/

Ultrasonix, http://www.ultrasonix.com

Visualsonics, http://www.visualsonics.com/

Zonare Medical Systems, http://www.zonare.com/

NB: *The list is not exhaustive!*

References

[Alizad *et al.* 2008] Image features in medical vibro-acoustography: In vitro and in vivo results

[Bossy *et al.* 2005] Fusion of conventional ultrasound imaging and acousto-optic sensing by use of a standard pulsed-ultrasound scanner

[Culjat *et al.* 2009] Polyimide-based conformal ultrasound transducer array for needle guidance

[Doyle *et al.* 2009] Simulation of elastic wave scattering in cells and tissues at the microscopic level

[Eames *et al.* 2009] Selectable frequency CMUT with membrane stand-off structures

[Ellis *et al.* 2007] A spline-based approach for computing spatial impulse responses

[Ellis *et al.* 2010] Super-resolution image reconstruction using diffuse source models

[Garland *et al.* 2008] Parallel computing experiences with CUDA

[Gémes 2010] CARESTREAM cookbook: something nice, quickly (in Hungarian). Presented at the 24th Ultrasound Days in Sopron conference.

[Gyöngy and Coussios 2010] Passive spatial mapping of inertial cavitation during HIFU exposure

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References

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[Harris 2007] Architecting new dimensions of medical imaging. http://download.intel.com/design/embedded/medical-solutions/medical_imaging.pdf

[Laufer *et al.* 2010] Photoacoustic imaging of vascular networks in transgenic mice. http://www.medphys.ucl.ac.uk/research/mle/pdf_files/BIOS2010_JL_manuscriptF.pdf

[Lemor *et al.* 2004] Mechanical properties of single cells: Measurement possibilities using time-resolved scanning acoustic microscopy

[Mo *et al.* 2008] Compact ultrasound scanner with simultaneous parallel channel data acquisition capabilities

[Roska] Personal communication

[Tortoli *et al.* 2009] ULA-OP: an advanced open platform for ultrasound research

[Vlad *et al.* 2010] An increase in cellular size variance contributes to the increase in ultrasound backscatter during cell death

[Weiss *et al.* 2007] Mechanical properties of single cells by high-frequency time-resolved acoustic microscopy

[Zhou *et al.* 2010] Micro-machined high-frequency (80 MHz) PZT thick film linear arrays