Research in Ultrasonic Imaging Laboratory

National Taiwan University

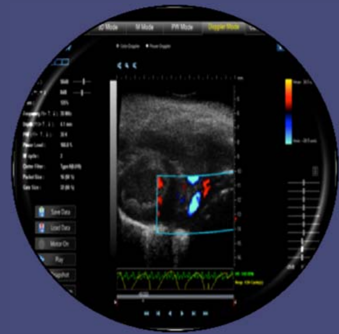
Ultrasound technologies for biomedical applications

Physics

- Wave propagation
- Ultrasound
- Photoacoustics

Systems

- Native SW imaging
- Hybrid architecture
- Functional imaging
- Customized Sensors



Imaging

- Adaptive imaging
- Software imaging
- Quantitative assessment

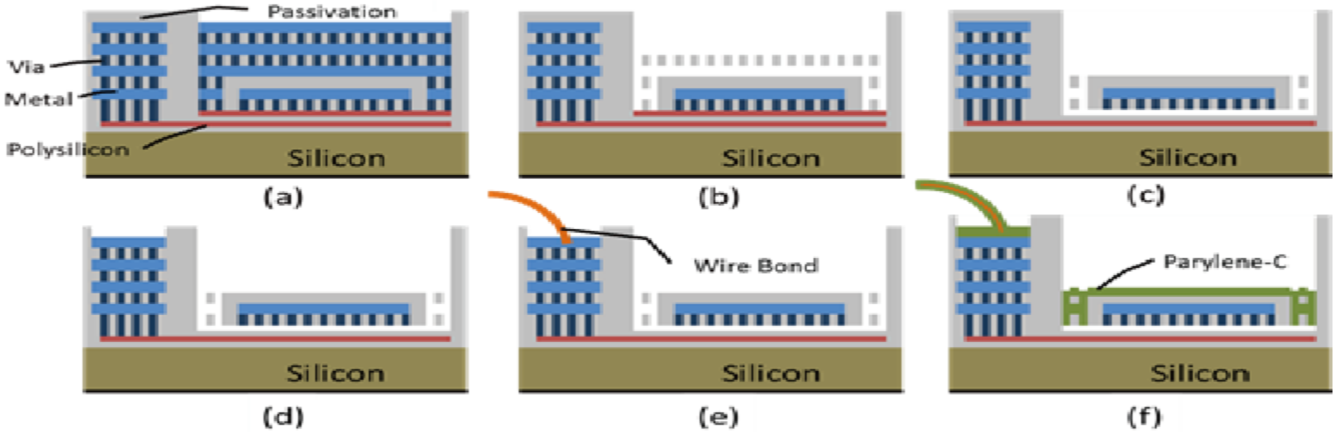
Imaging Devices

CMOS-MEMS capacitance micromachined ultrasonic transducer

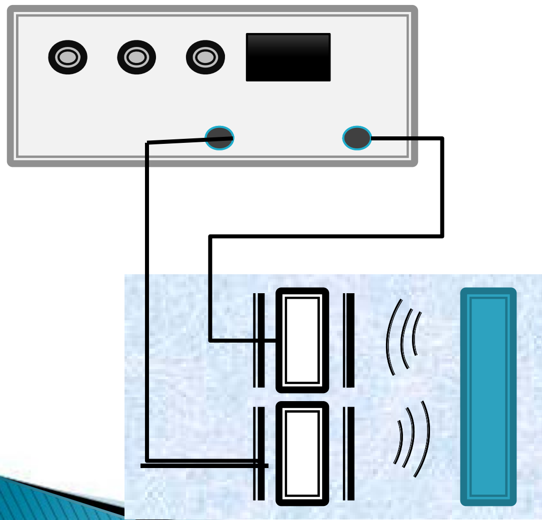
- Goal: Develop an ultrasonic transducer operating in low voltage utilizing TSMC 0.35um CMOS-MEMS fabrication.

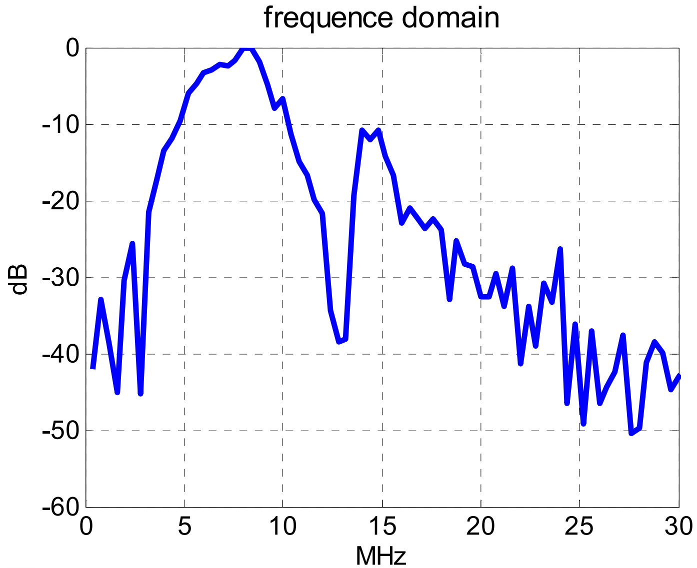
- Hypothesis:
  - Release the poly-silicon as the gap of CMUT to lower the operating voltage.
  - Separately design the transmitting and receiving modes to optimize measurements of the CMUT.

- CMUT processing



- Pulse echo measurement





DC 20V	
fc	7.27MHz
FBW	57.2%
Vpp(V)	0.528

NTUBEBI Ultrasonic Imaging Laboratory

Development of high frequency ultrasound transducers for biomedical imaging

- Goal: Design and fabrication various forms and frequencies of high frequency ultrasonic transducers.

- Hypothesis: High frequency (>20MHz) ultrasound transducer have high spatial resolution but limited depth of penetration. In order to get the best quality of medical imaging, this study manufacture various forms and frequencies of high frequency ultrasonic transducers for various imaging applications.

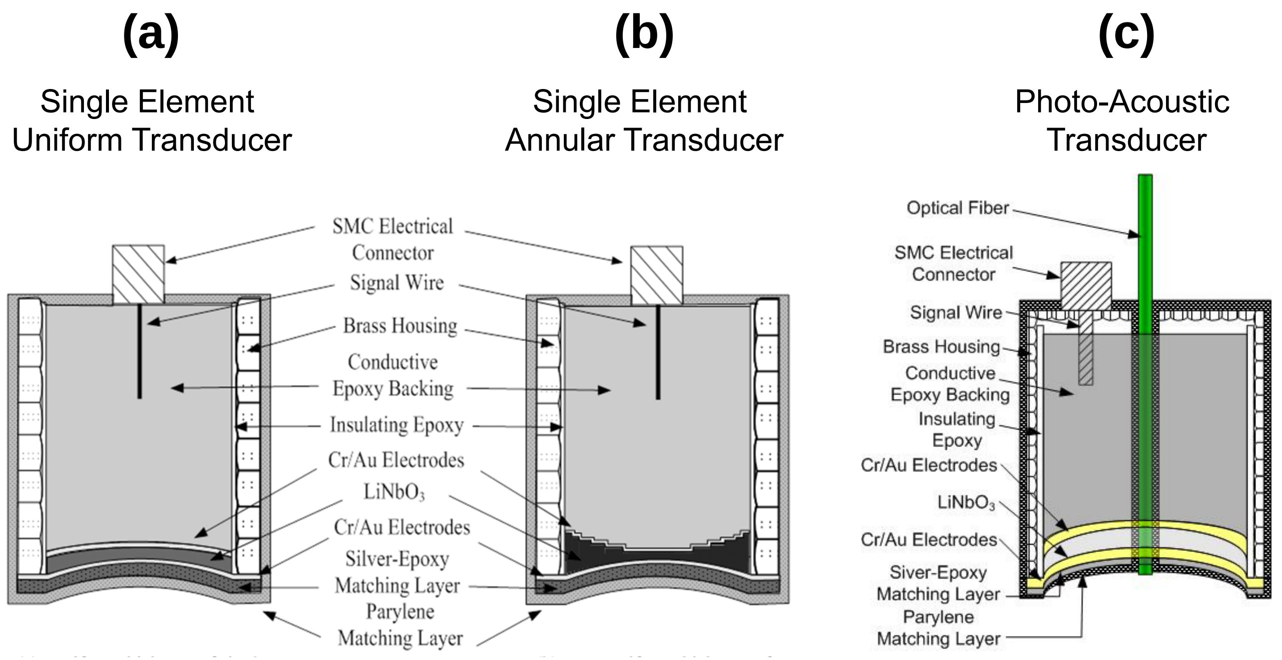


Fig.1 Schematic diagrams of the SEUT(a), SEAT(b) and PAT(c).

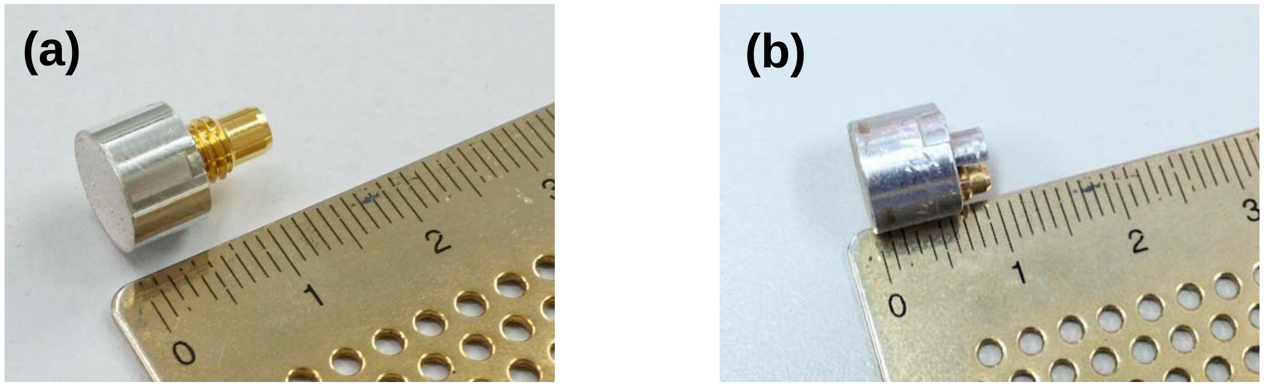
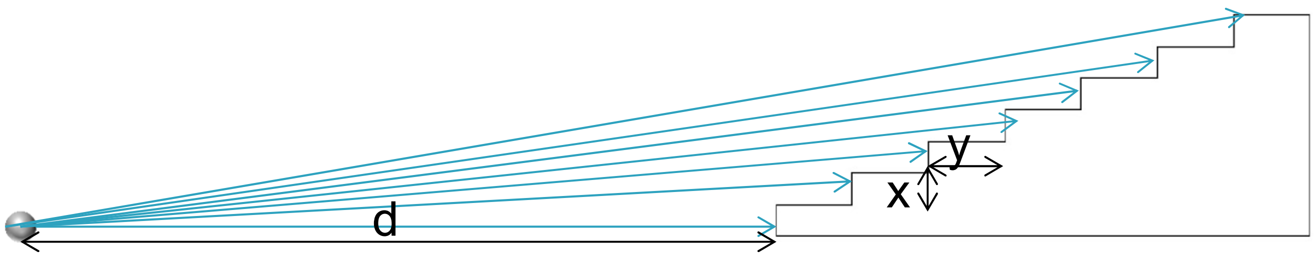


Fig.2 Photographs of finished SEAT(a) and PAT(b).

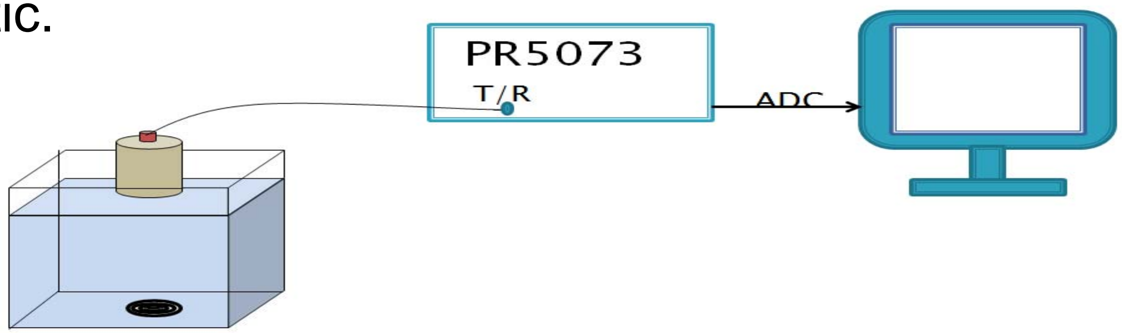
Detection of implanted device using ultrasound

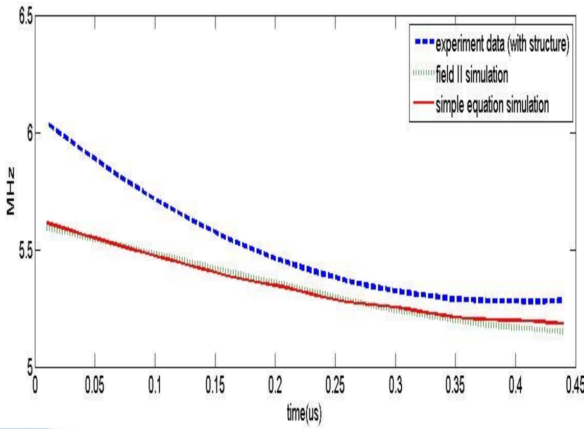
- Goal: Verify the implanted device at the focal point for robust and efficient wireless data and power transmission.
- Hypothesis:
  - Maya pyramid which is stair-shaped causes the echo to have the characteristic that the frequency decrease over time.
  - The round trip distance difference between each step :



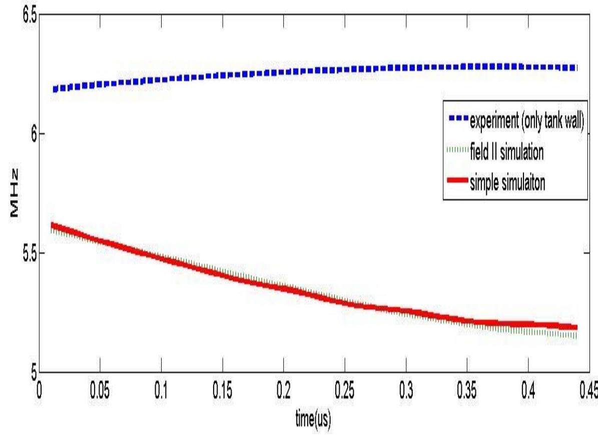
$$\Delta S(i) = 2\sqrt{[d+(i)\times x]^2 + (i\times y)^2} - 2\sqrt{[d+(i-1)\times x]^2 + [(i-1)\times y]^2}$$

- ΔS is not constant, so the echo has the characteristic that frequency decrease over time.
- It is possible to using this characteristic for verifying that the device is located at the focal point.
- This shows that the maya structure cause the echo's frequency decrease over time. And other such as flat wall cannot have that characteristic.





Maya structure



Tank wall

Optical generation of narrowband high frequency ultrasound

- Goal: To develop an optical narrowband high frequency ultrasound transducer.
- Hypothesis: An optical narrowband high frequency ultrasound transducer can easily separate US and PA signal by frequency domain.

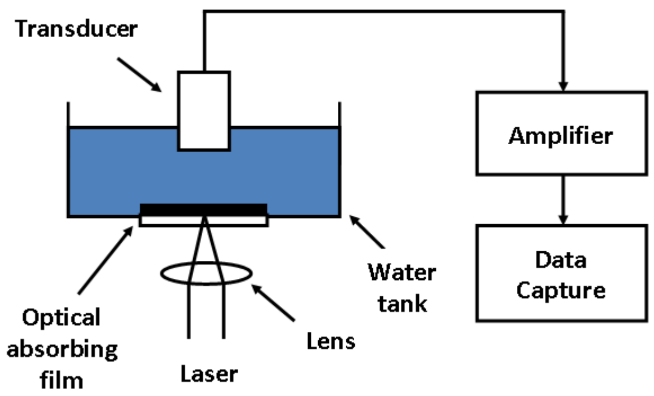


Fig. 1 Block diagram of experiment for thermoelastic generation of ultrasound.

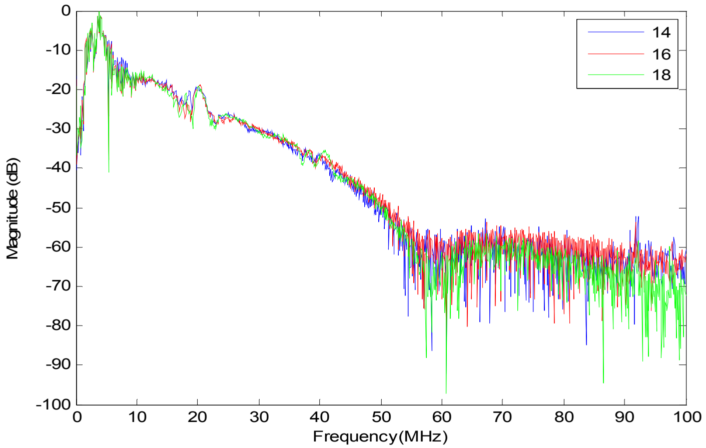
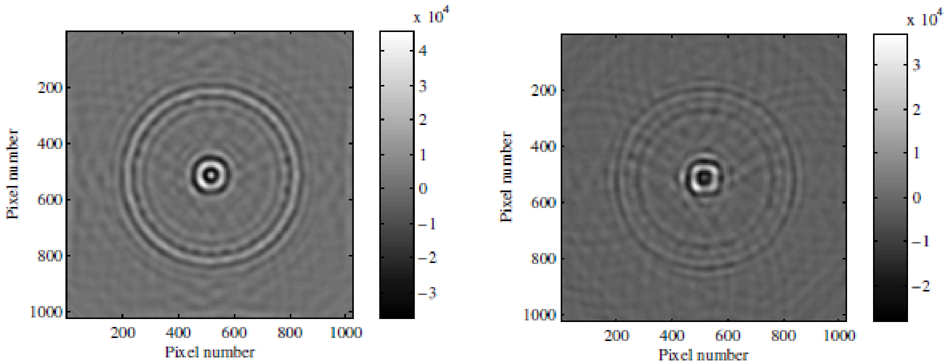


Fig. 2 Spectrum comparison of the PDMS film with different laser pumping energy.

Imaging Systems

Information theoretic analysis of ultrasound imaging

- Goal: To derive an information-theoretic image quality assessment scheme, such that the change in information during the compression process of ultrasonic signals can be quantified and traced, hopefully to become a help in deriving optimal compression scheme.



(a) (b)

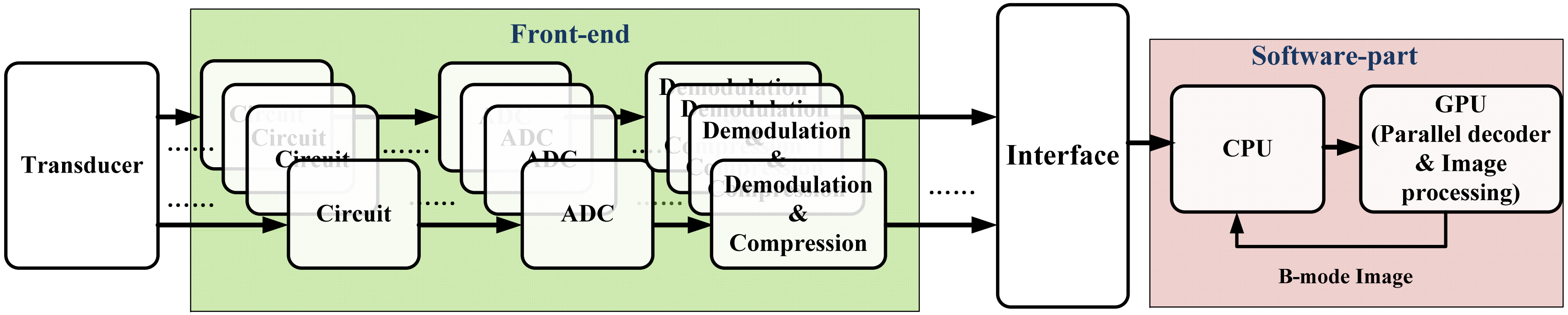
Ultrasound images (a) before and (b) after compression (R. Liu, 2011)

- Hypotheses:
  - Clinically meaningful information can be quantified and traced.
  - Information-theoretic approaches are more consistent with the human visual system than traditional approaches (e.g., MSE, PSNR).
  - The task of lesion detection can be modeled as a hypothesis testing problem.

Noisy images with the same MSE but different perceptual feelings.
(H. Zhu *et al*, 2005)

Real-time implementation of lossless data compression for native SW imaging

- Goal : Using Data compression with Parallel decoder to (1) mitigate the transmission bandwidth requirement of hardware interface and (2) reduce the transmission time of software memory copy



Interface :

USB 3.0 / PCIE

- Hypothesis : With the fast computation ability of GPU, the transmission time of transferring compressed data with parallel decoding process is less than transferring original signals, as thus, the transmission time of software memory copy can be reduced

- Encoder and decoder design:
  - To truncate unnecessary bits within a batch data
  - By using extra address information, bit information and location of samples for different batch can be recorded. Decoder can be decompressed samples in parallel with address information
  - Compression ratio of 1.5-1.7 can be achieved by the lossless compression

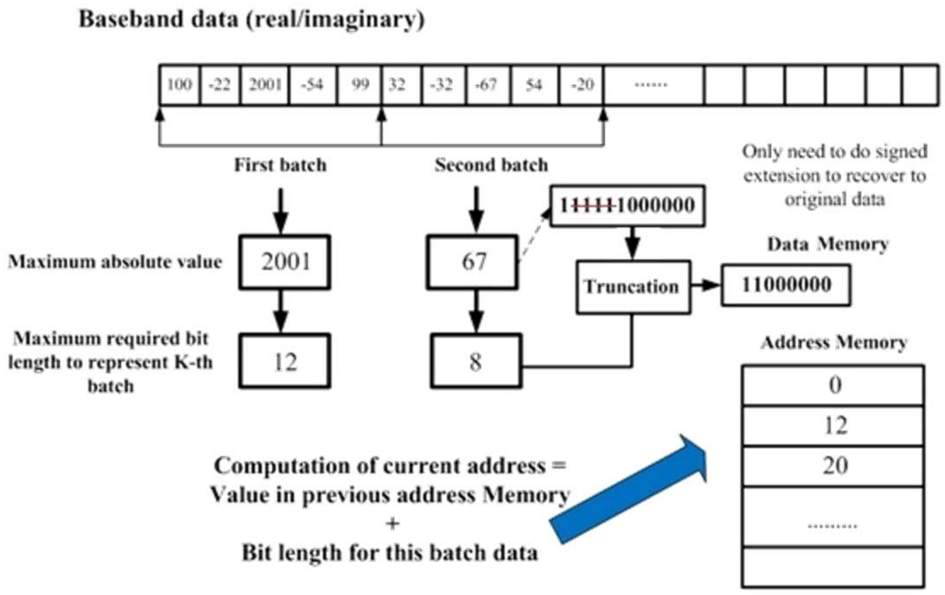


Fig. 1 Illustration diagram for batch-based lossless compression.

Conditions in GPU	Execution time(ms)
Transfer 16 bit RF data	16.12
Transfer 16 bit Baseband data	8.54
Transfer compressed data	3.82
Parallel Decoder	3.47
Transfer compressed data + decoder	7.29

TABLE 1 Comparison of GPU's execution time with and without data compression

Ultrasound image quality optimization with adaptive global sound speed correction

- Goal : To detect the global sound speed from the image and optimize the image quality automatically.

- Hypothesis :
  - Imaging with true sound speed will lead to better spatial and contrast resolution.
  - The correct global sound speed can be detected from image analysis.

Representative Figures :

Using central and sides sub-apertures to imaging separately, and detect the correct sound speed automatically with minimum mean error of these two images.

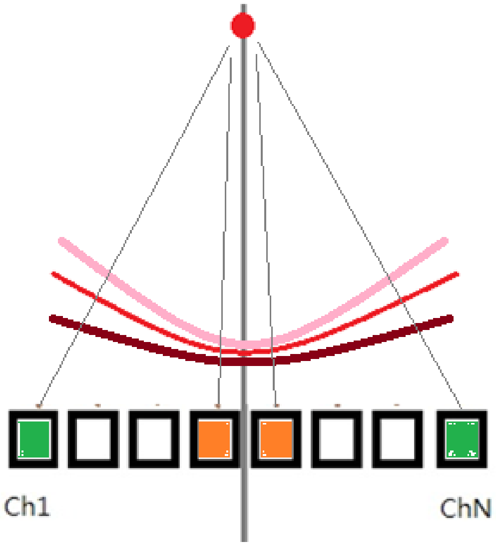


Fig.1 Different delay profile due to different sound speed.

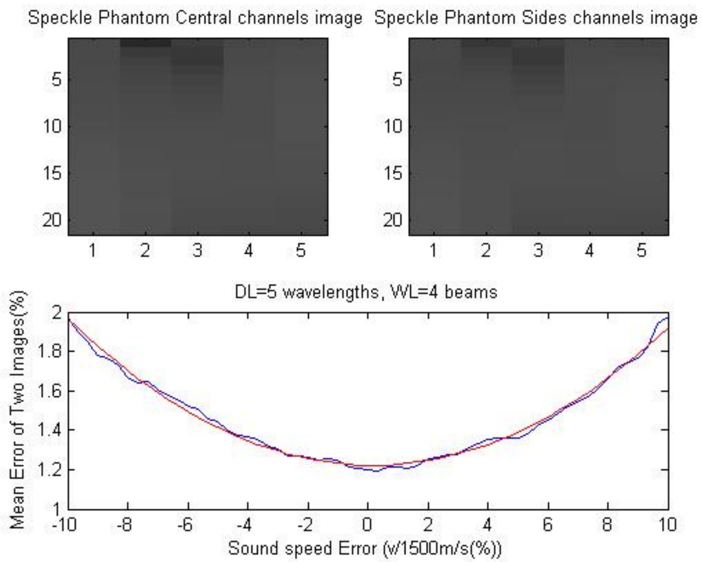


Fig.2 Mean error of two images to multi sound speed scan

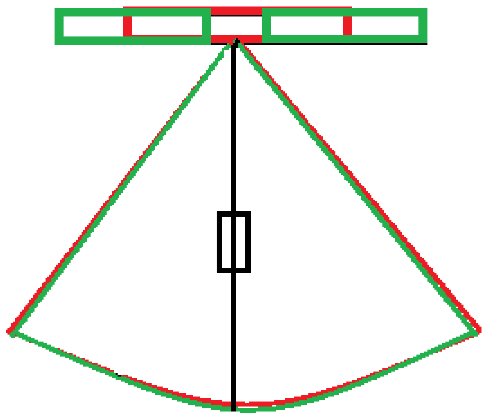
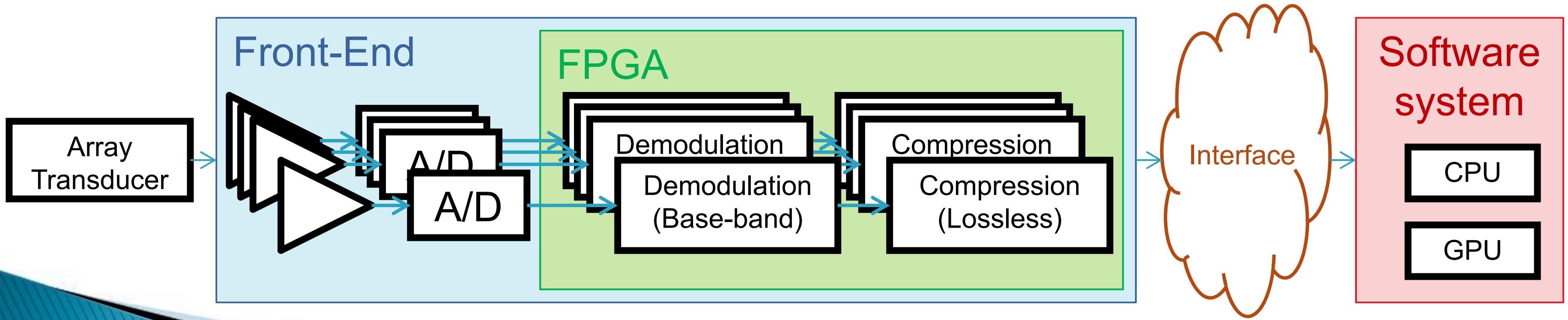


Fig.3 Central and sides sub-aperture imaging

Efficient FPGA implementation of lossless data compression

- Goal: Reducing data size to break the transmission bandwidth limitation.
- Hypothesis:
  - Implementing demodulation and compression can effectively lower the data size, hence decrease the bandwidth requirement.
  - The overall processing time including demodulating, encoding, transmitting, and decoding would be less than the original one, which only transmits the raw data.



GPU-based parallel beamforming for real-time 3D ultrasound imaging

- Goal: To develop a software-based parallel beamforming method for achieving real-time 3d ultrasound imaging system.

- Hypothesis :
  - GPU's high performance in parallel computing makes software based imaging system possible.
  - Decrease the aperture data needed may overcome data transfer bottleneck in software-based imaging system.
  - Degraded image quality can be compensated by adaptive weighting techniques.

Representative Figure

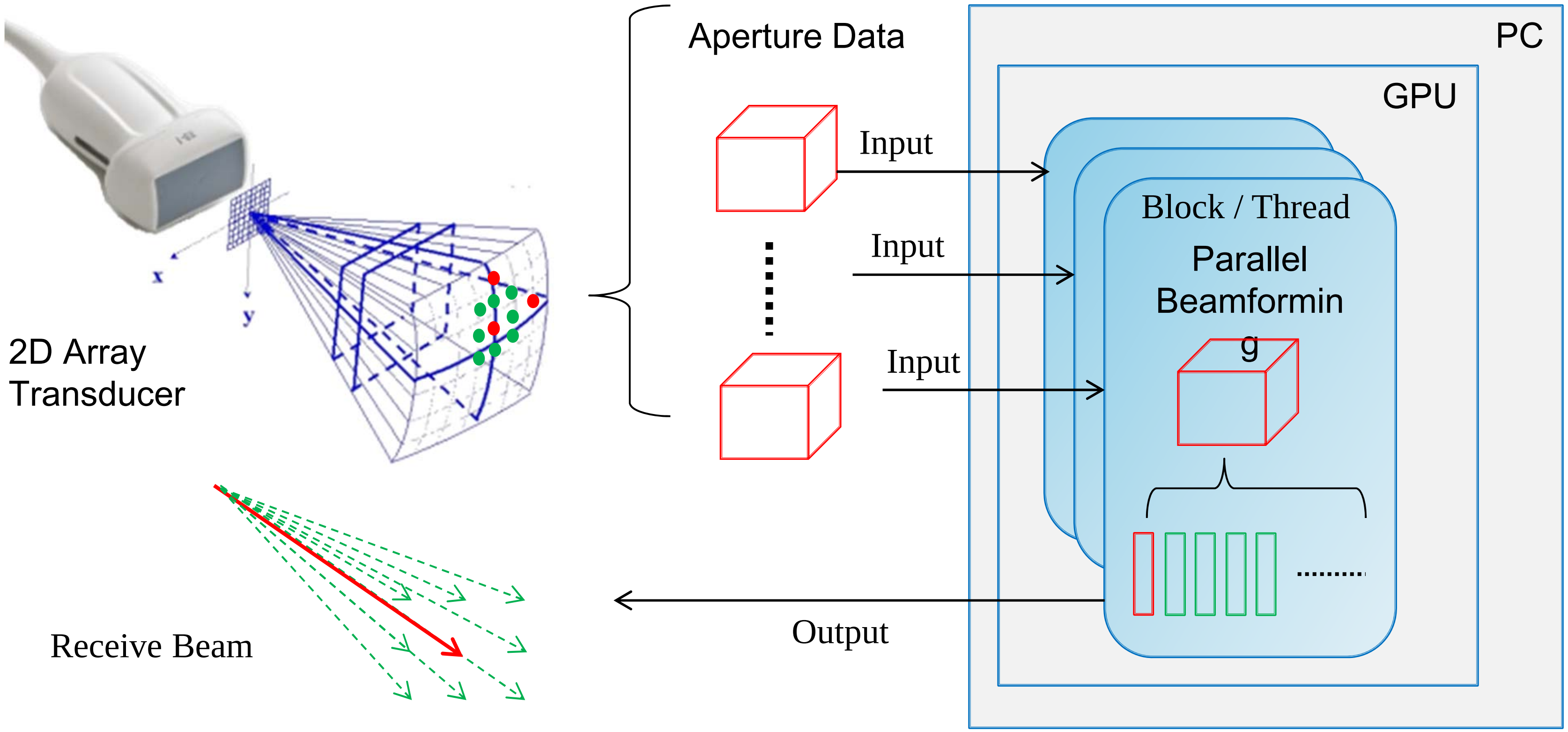


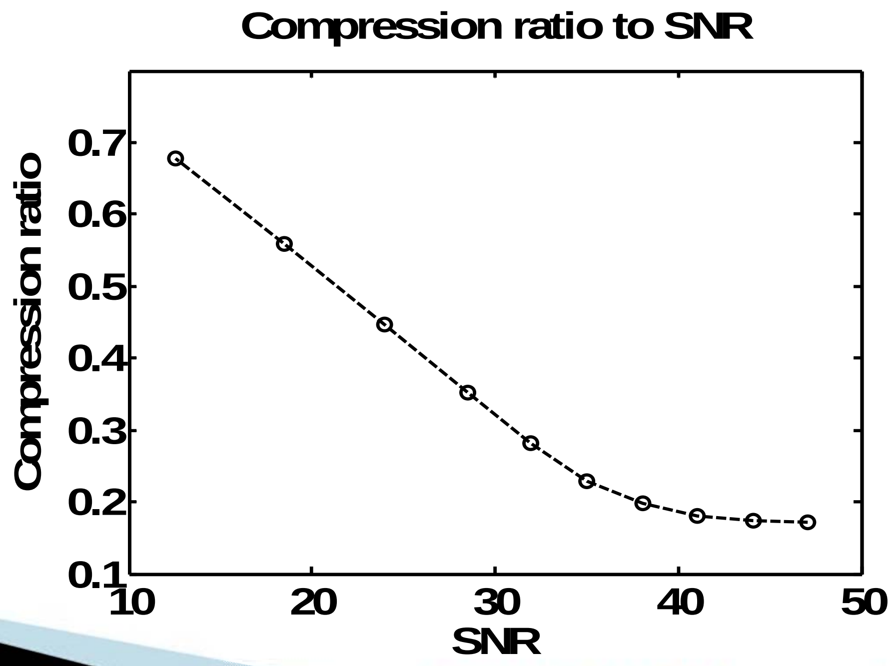
Fig.1 Flow chart of parallel beamfroming

Channel data compression for SW doppler imaging

- Goal: Perform SW based real-time color Doppler imaging with limited data transfer bandwidth.

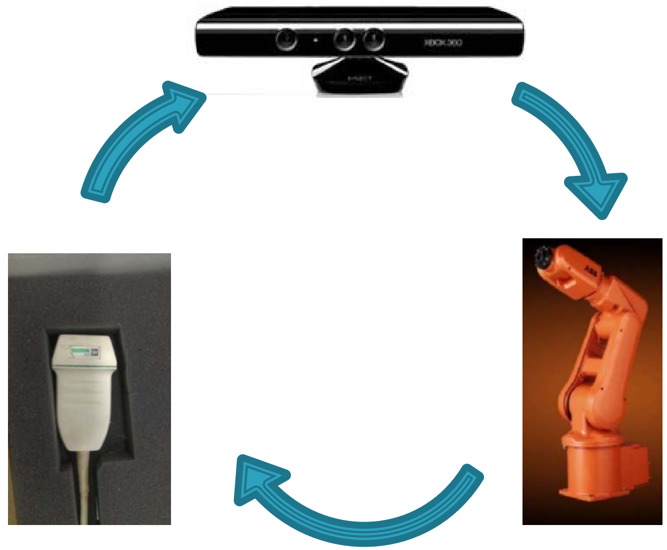
- Hypothesis:
  - Redundancy between Doppler ensembles can be removed by using MPEG compression.
  - Background noise can be abandoned during the encoding process to reduce the data size and maintain the correctness of flow information.

- MPEG compression of Doppler channel data
  - Efficiency degrades with SNR. In lossless mode, compression ratio is 0.2 at 40 dB SNR, and is 0.6 at 6 dB SNR.
  - Background noise can be distinguished and abandoned. In 6 dB SNR case, the compression ratio can be reduced from 0.6 to 0.3.

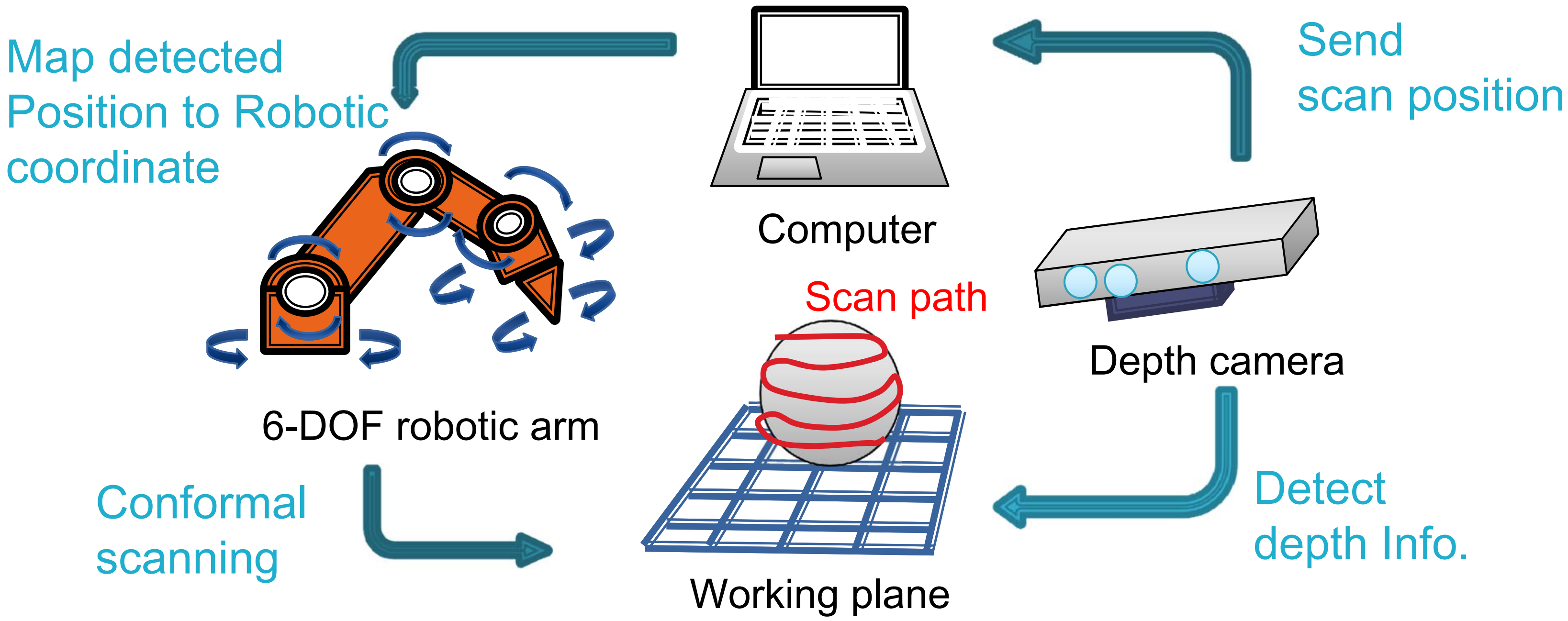


Automatic conformal scanning for disease screening

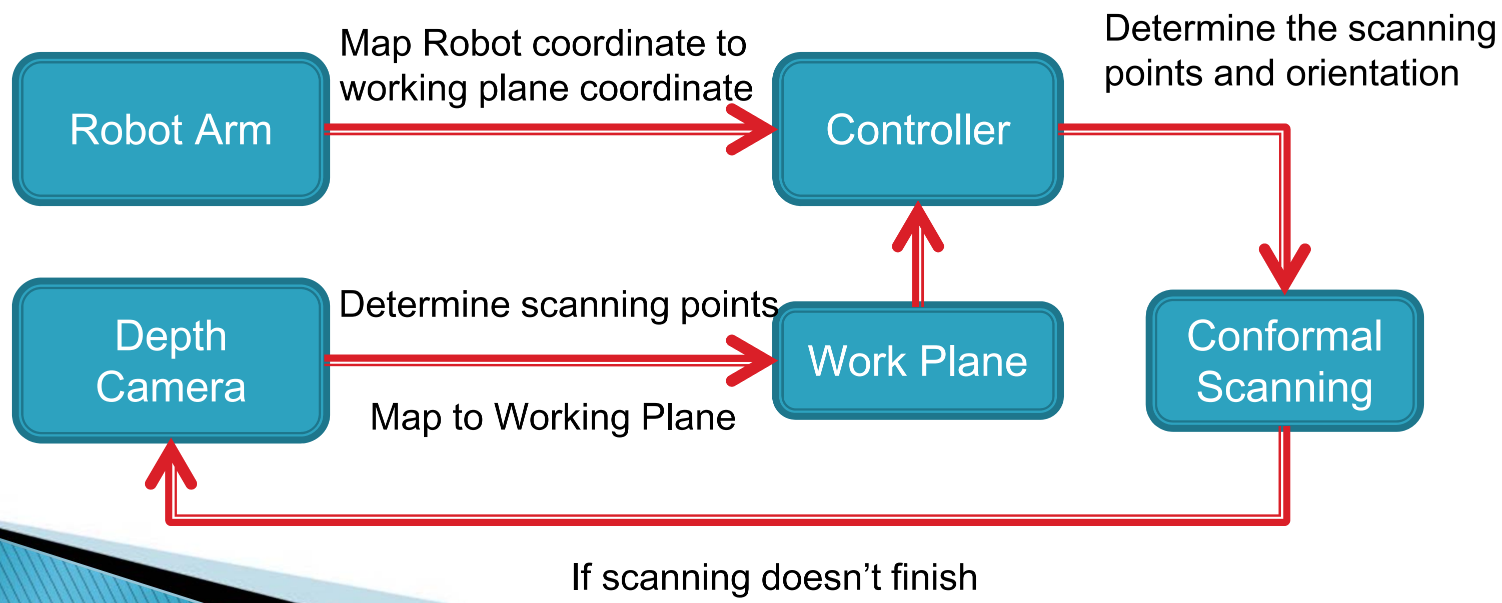
- Goal: Realizing conformal scanning with assistance from depth camera and robotic arm.



- Hypothesis:
  - The location and surface of imaged object can be reconstructed from data received using depth camera.
  - The transformation matrix can be used to map position from depth camera coordinate to robotic arm’s.



Map detected
Position to Robotic
coordinate
Computer
Send
scan position
6-DOF robotic arm
Scan path
Depth camera
Conformal
scanning
Working plane
Detect
depth Info.



Robot Arm
Map Robot coordinate to
working plane coordinate
Controller
Determine the scanning
points and orientation
Depth
Camera
Determine scanning points
Work Plane
Conformal
Scanning
Map to Working Plane
If scanning doesn't finish

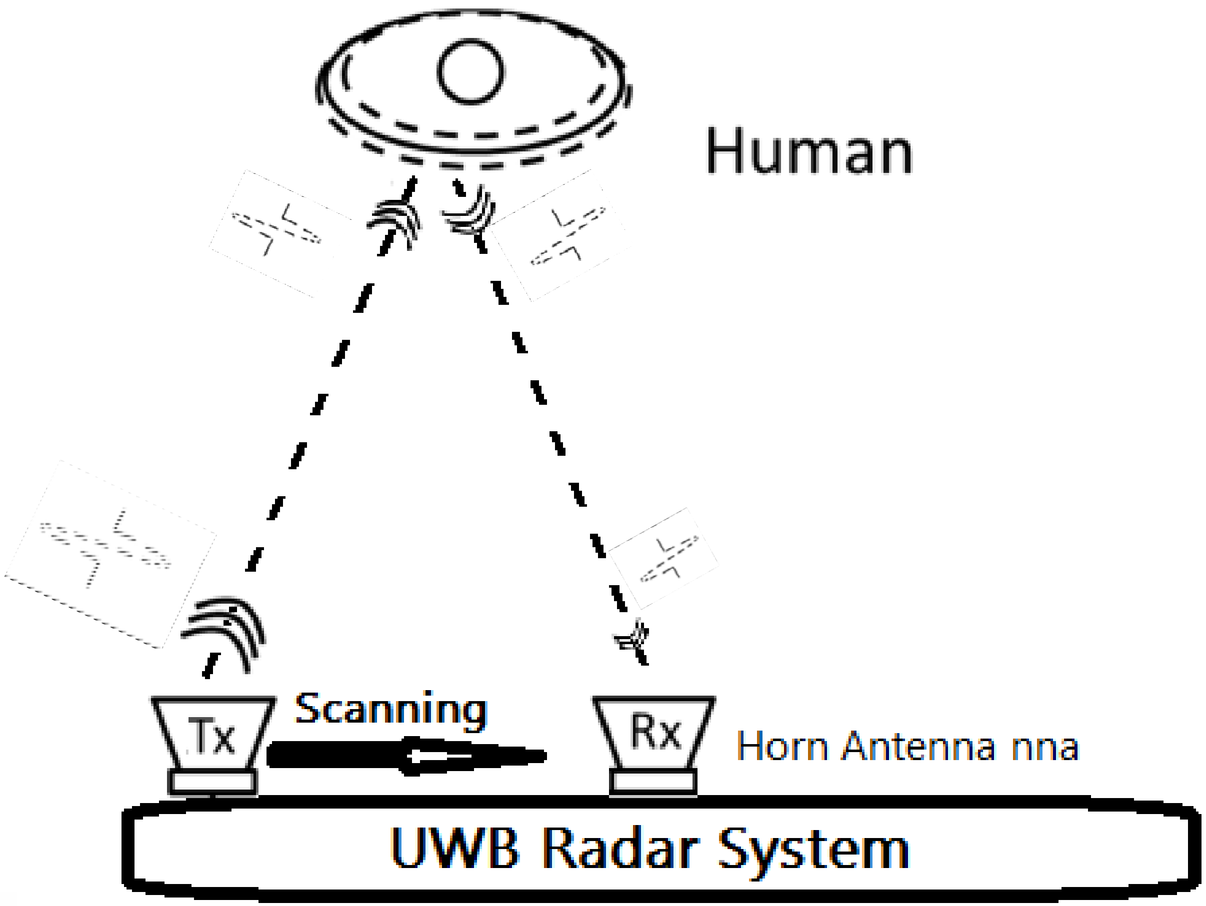
Ultra-wideband respiration detection

- Goal: Using ultra-wideband radar (UWB) to achieve human respiration motion detection and estimation.

- Hypothesis
  - Human respiration motion brings about small range variation between the object body surface and radar which can be estimated with signal processing techniques on the received UWB signal.
  - Using UWB radar to scan on area of interest, the position of object and its respiration motion can be determined after received UWB signal processing.

- Representative figure

  Measuring human respiration motion with UWB radar.



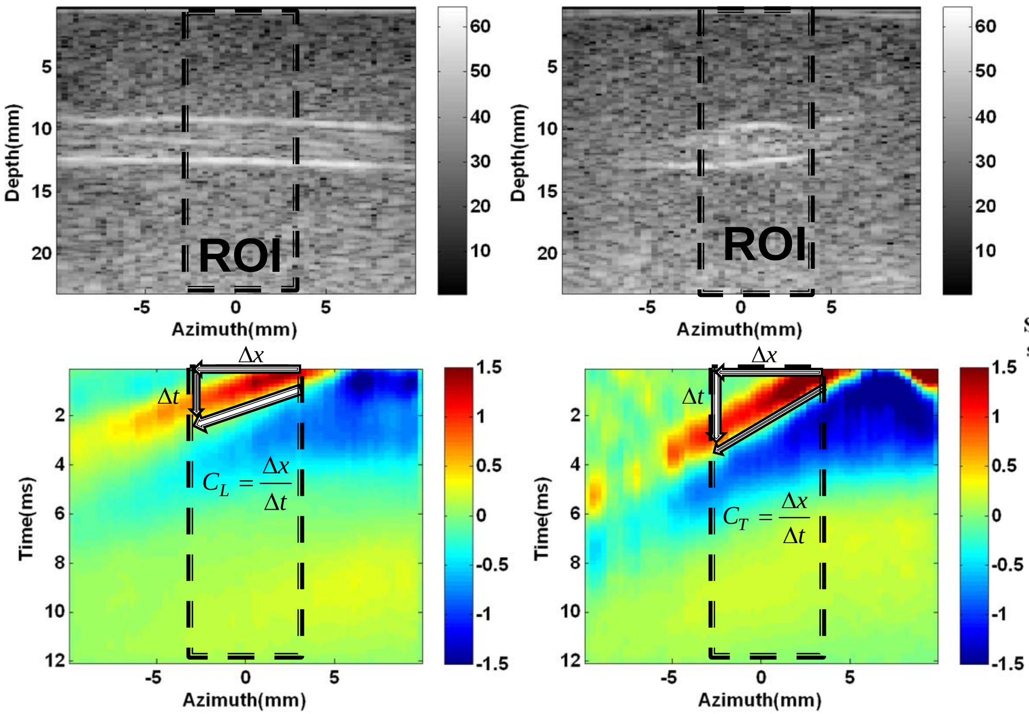
Shear Wave Imaging

Ultrasonic shear wave elasticity imaging (SWEI)

- Goal: Noninvasively investigation of anisotropic elasticity properties of tendon using SWEI .
- Hypothesis:
  - Structure changes of collagen fiber network caused by diseases may alter the anisotropic properties of tendon.
  - Correlation between the shear wave speed and anisotropic elasticity properties of tendon is valid.

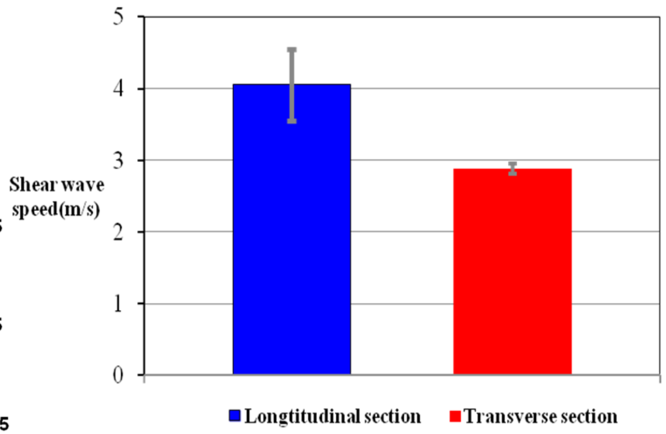
- Representative figures:

The anisotropic elasticity properties of tendon can be quantitatively estimated by SWEI.



Longitudinal section

Transverse section



Shear wave elasticity imaging for preclinical studies

- Goal
  - To develop a shear wave elasticity imaging system for preclinical research on small animals.
  - To combine the push transducer and detection transducer, and to use mechanical scanning to perform elasticity imaging.
- Hypothesis:
  - High-frequency elasticity imaging can provide more accurate elasticity information of small animals.

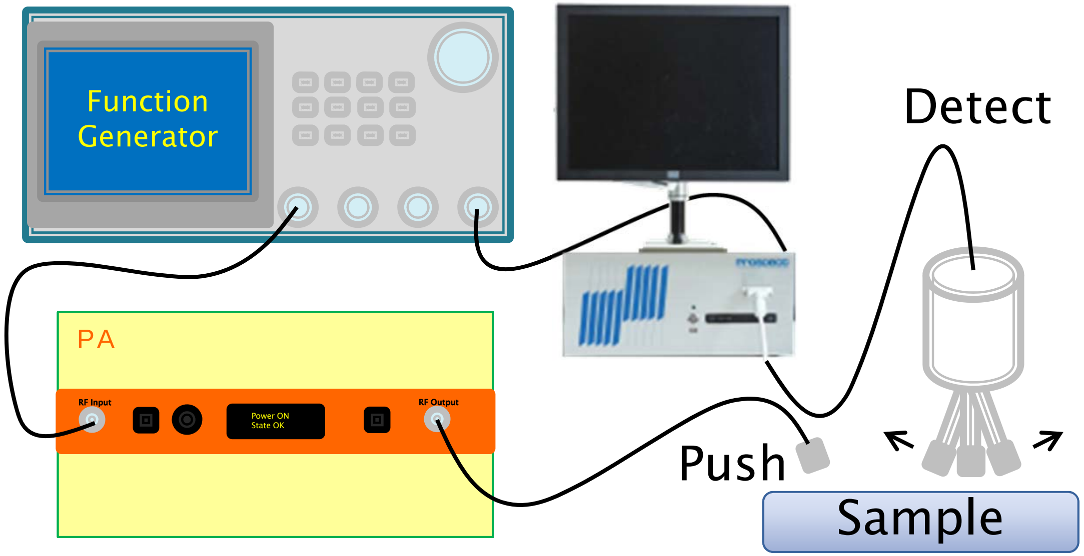


Fig. 1. System setup

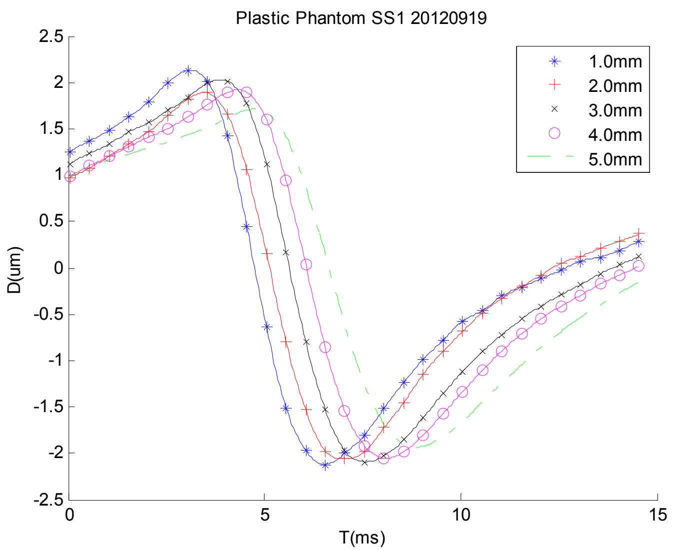


Fig. 2. Results of shear wave

Plastic Phantom		
Hardener	Softener	Elasticity
30ml	70ml	14.81kPa
40ml	60ml	25.39kPa
50ml	50ml	33.33kPa
60ml	40ml	48kPa

Fig. 3. Elasticity of other phantoms

Evaluating the effect of cells on phantom elasticity

- Goal: To quantify the change of viscoelasticity in a 3D cell culture system using shear wave speed measurement

- Hypothesis: The remodeling of ECM due to cell activities can be quantitatively assessed by elasticity measurement

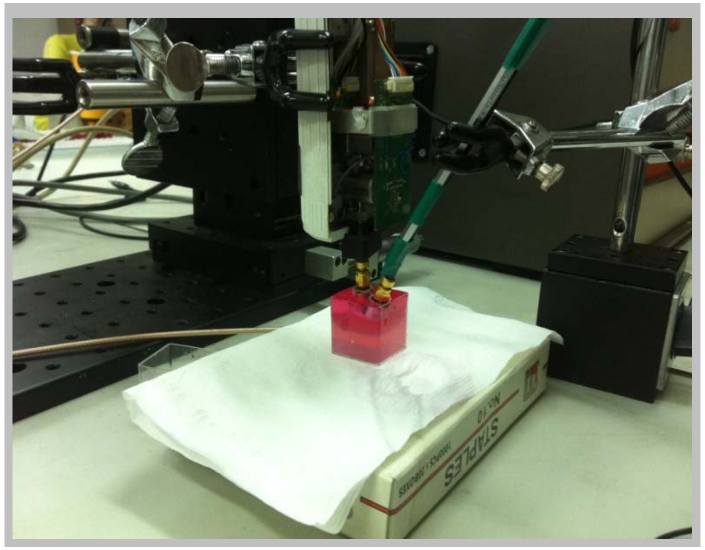


Fig.1

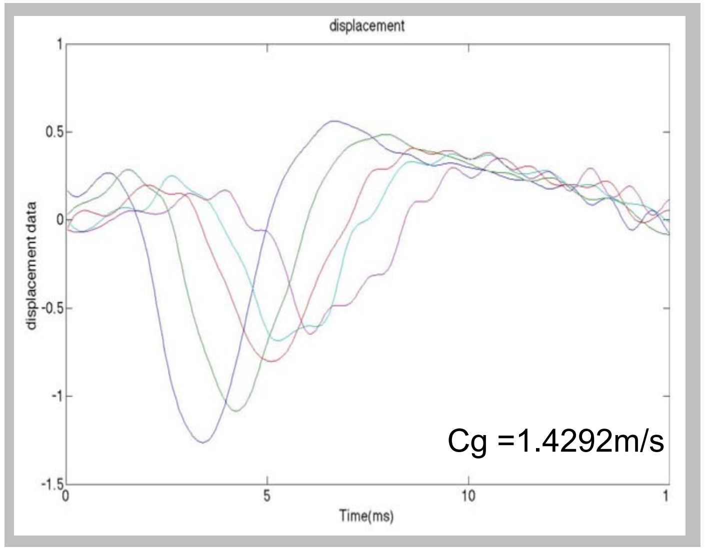


Fig.2

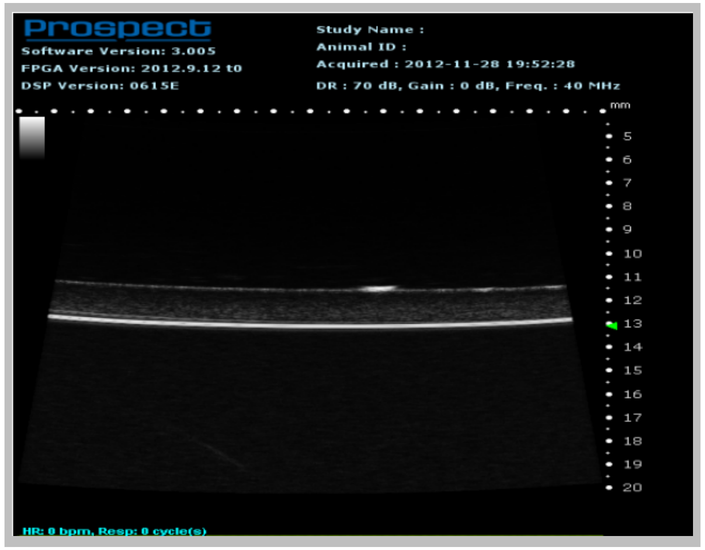


Fig.3

- Fig.1 Using high frequency ultrasound system to measure the elasticity of the collagen phantom.
- Fig.2 Calculating elasticity depending on μ=ρ*Cg^2 (μ:shear modulus, ρ:density, Cg: group velocity of shear wave)
- Fig.3 The B-mode image of cell distribution (without scatters)

3D cell culture model reconstruction

- Goal: Get the ideal physical quantities to verify the experimental results

- Hypothesis:
  - Suppose an mechanical wave generated by probe focus ultrasonic beam at given location to create volumic radiation force.
  - The mechanical displacement induced by such a volumic force in the medium can be calculated by ABAQUS.

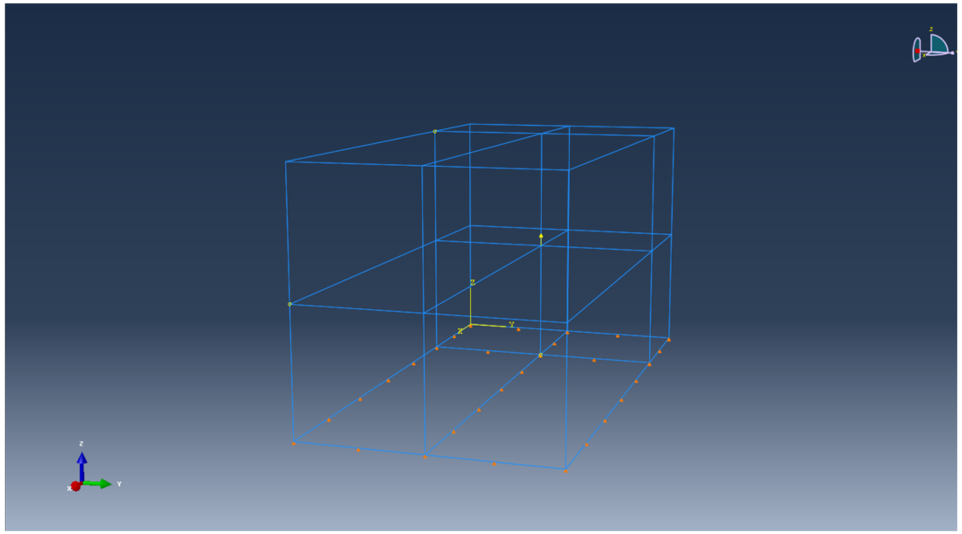


Fig. 1. phantom structure and applied force

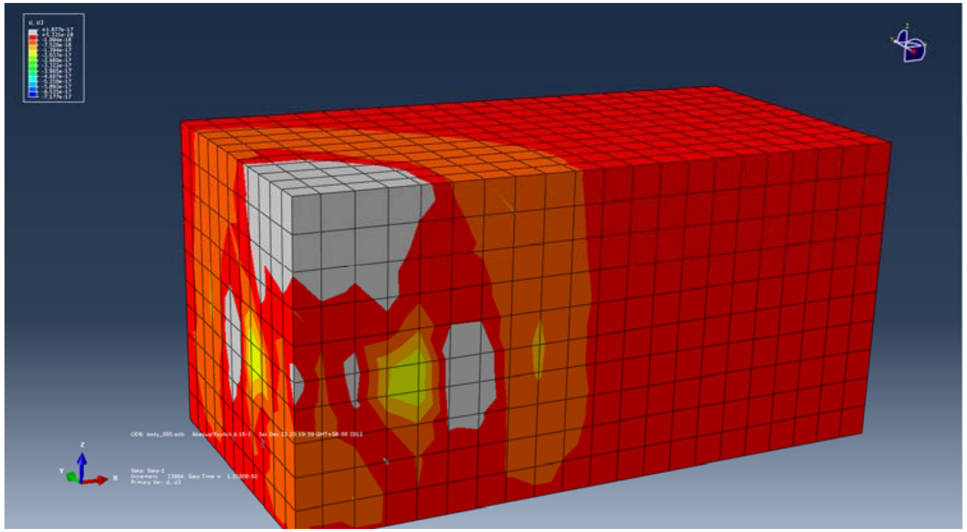


Fig. 2. wave propagation in phantom

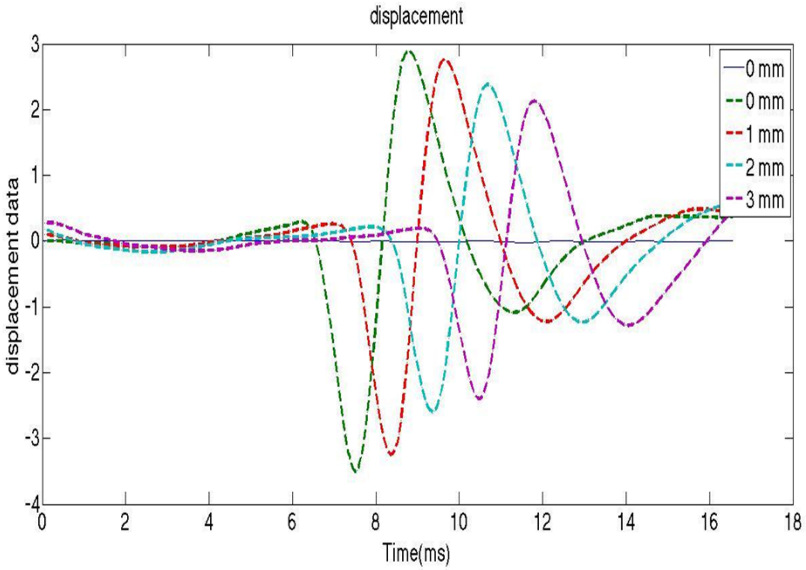


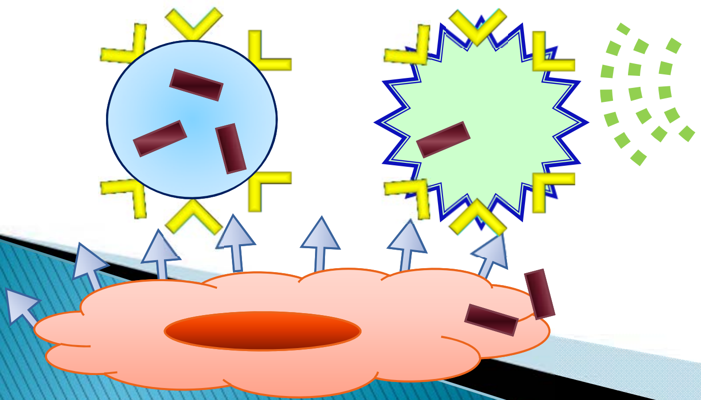
Fig. 3. Experimental results

Theranosis

Enhanced delivery of nanoparticles with microbubbles

- Goal: Improved diagnosis and therapeutic efficacy by two-stage targeting and controlled release of nanoparticles.

- Hypothesis:
  - Active targeting with surface modification and ultrasound mediation (such as radiataion force and cavitation) can enhance delivery of nanoparticles.
  - This process is observed by US/PA/optical imaging



Representative figures

Fig. 1 US/PA image of AuMB

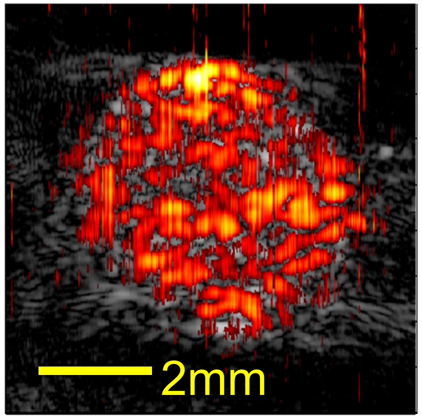


Fig. 2 Sonoporation

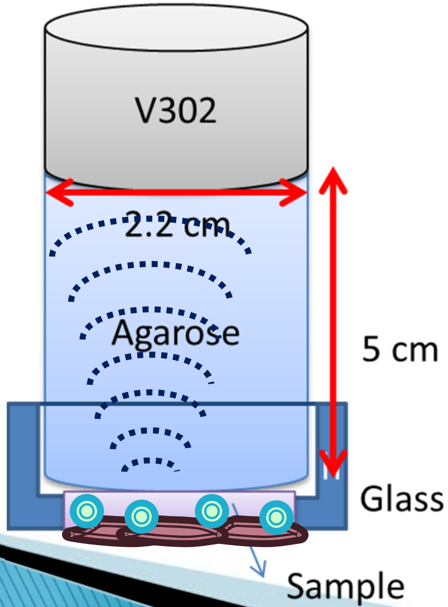
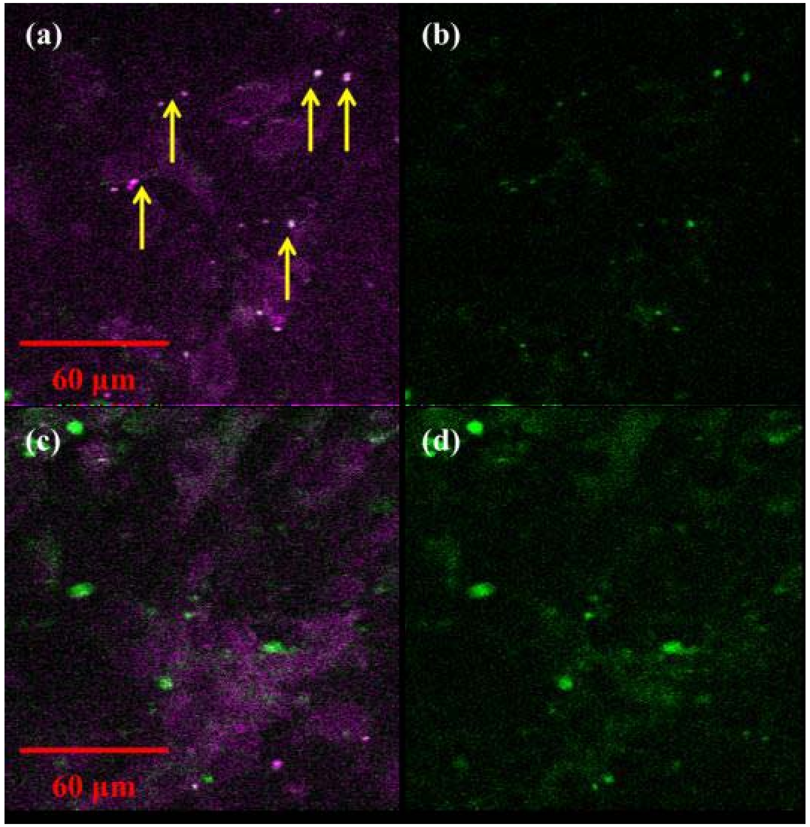


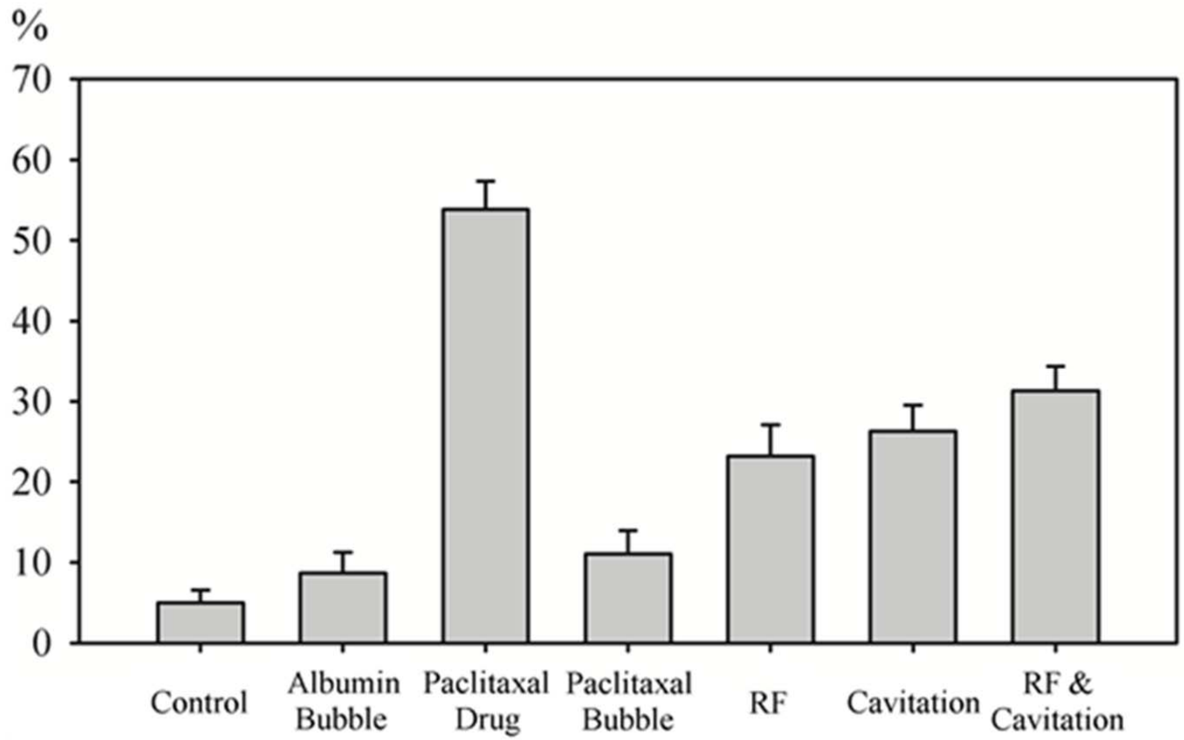
Fig. 3 Microscopy images before and after the US treatment



Paclitaxel-containing albumin microbubbles: application in breast cancer cell model with acoustic exposure

- Goal: Ultrasound application for local delivery of chemotherapeutic agent

- Hypothesis: Radiation force combined with cavitation increases apoptosis rate of breast cancer cell that exposed to paclitaxel-containing albumin microbubbles

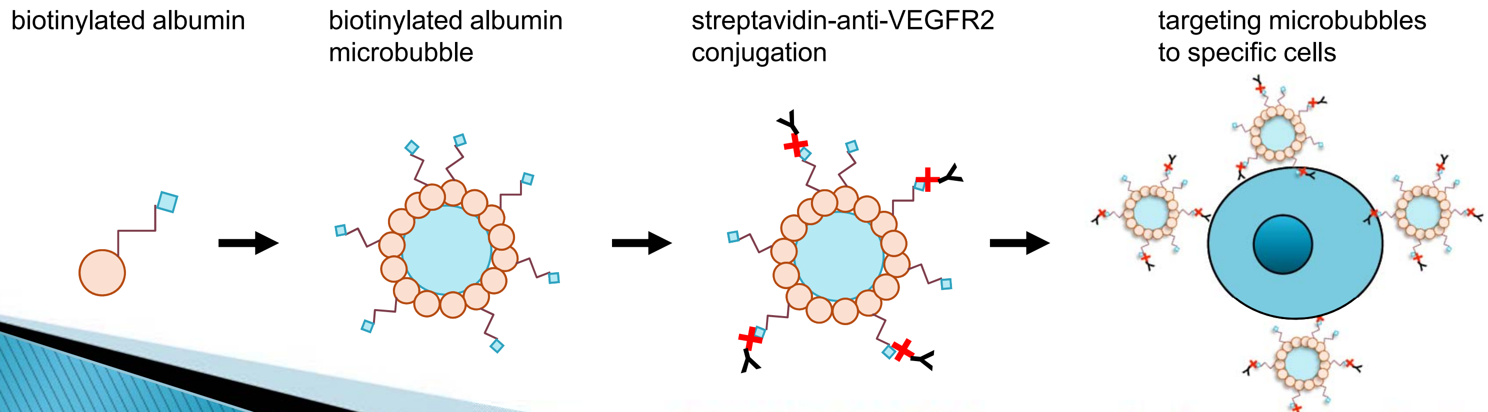


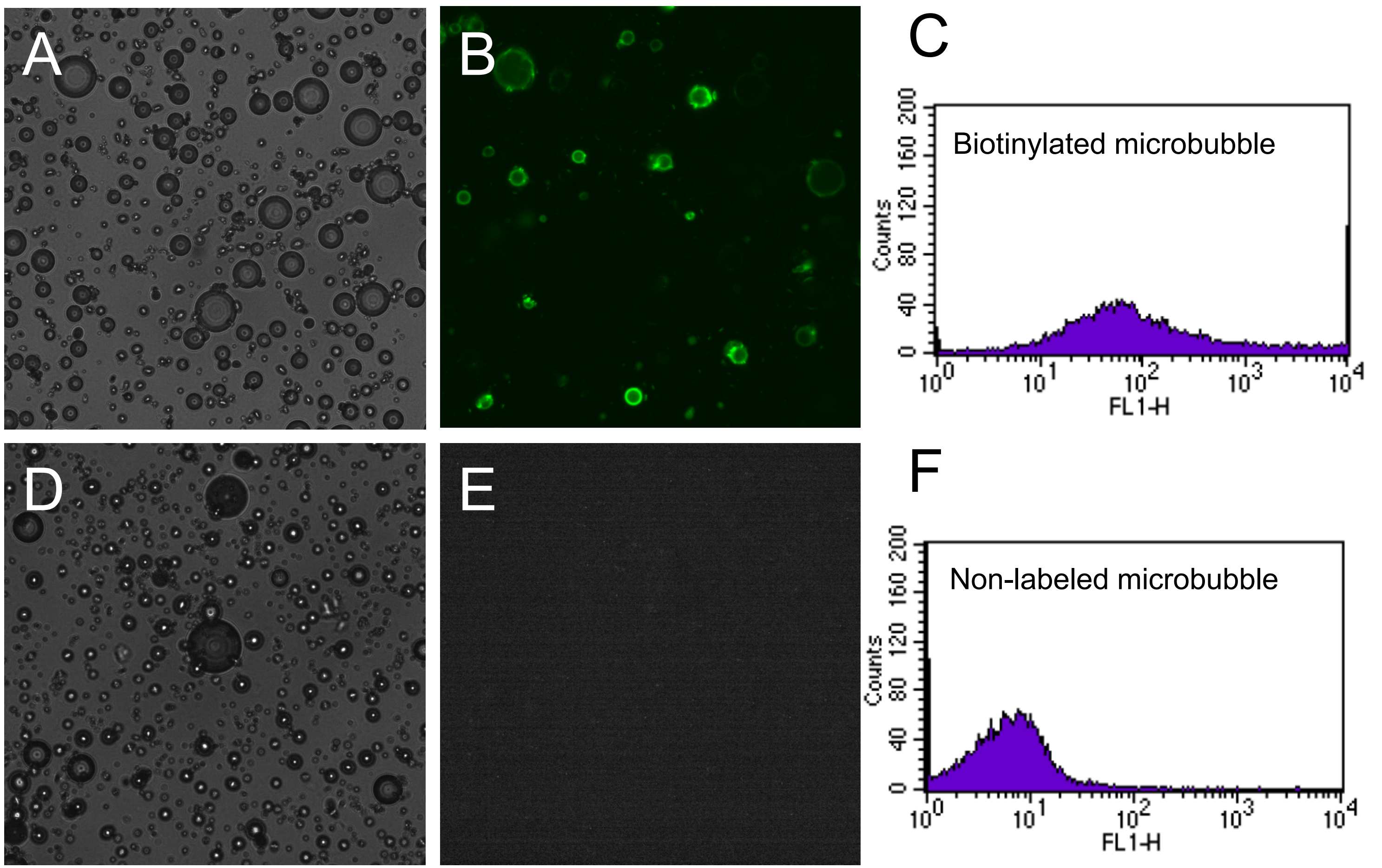
Apoptosis rate (Annexin-V) examined by flow cytometry. Radiation force alone increases 12.1% apoptosis rate, relative to cells that exposed to paclitaxel-loaded microbubbles. Cavitation alone increases 15.2% apoptosis rate, relative to cells that exposed to paclitaxel-loaded microbubbles. Combining radiation force and cavitation produces additional 20.2% apoptosis rate, relative to cells that exposed to paclitaxel-loaded microbubbles.

Biotinylated targeting-microbubbles for contrast enhancement and cell sorting

- Goal:
  - To enhance efficiency and the strength of targeting microbubbles as contrast agent in ultrasound imaging .
  - To use buoyancy of microbubbles to separate the circulating cells or the cells in suspension.

- Hypothesis: Enhancing the connection between the target cells and the microbubbles by bonding the streptavidin-anti-VEGFR2 to the biotin-conjugated microbubbles along with biotin-avidin interactions





Preliminary results of biotinylated microbubbles. (A, D) Biotin-conjugated microbubbles (MB) (A) or non-labeled MB (D) under bight field microscopy. (B, E) Biotin-conjugated MB (B) or non-labeled MB (E) stained with streptavidin FITC (green). (C, F) Quantification of biotin-conjugated MB (C, mean intensity = 974.37) or non-labeled MB (F, mean intensity = 10.29) with streptavidin FITC by flow cytometry.

Photoacoustic Imaing

Photoacoustic microscopy system

- Goal: To achieve biomedical photoacoustic microscopy with cellular resolution and sensitivity.

- Hypothesis:
  - Using near-field detection configuration and high optical-focusing setup to achieve micro-resolution.
  - Using 2-D high-frequency laser-scanner for optical focusing and illumination to achieve high temporal resolution.

Representative Figure

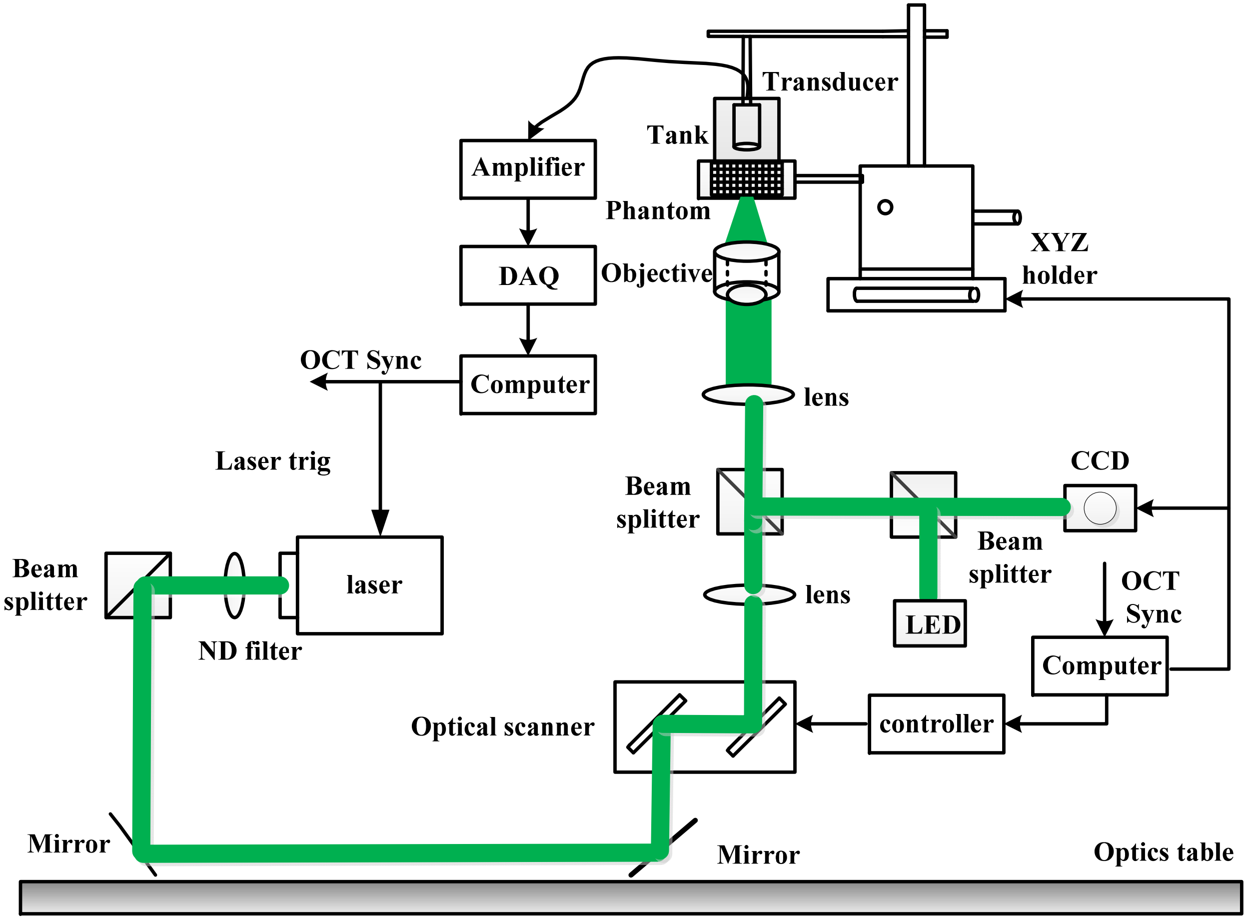


Fig. 1 Schematic of the optical-resolution photoacoustic microscopy system

Super-resolution motion tracking in PA imaging

- Goal: Develop algorithms for improving spatial resolution of photoacoustic imaging.

- Hypothesis:
  - The point-spread function (PSF) describes the image system response, which is a measure for the image system quality.
  - Finer motion details of the imaged objects can be reconstructed by deconvolving the captured image with the PSF.

- Representative figures:

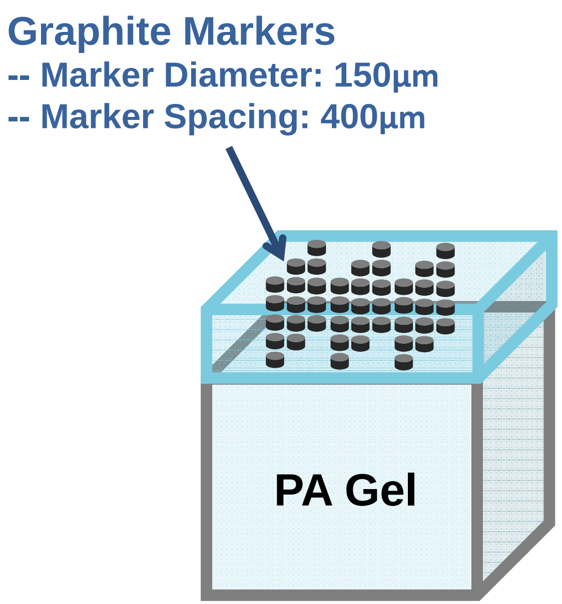


Fig.1 Imaged phantom

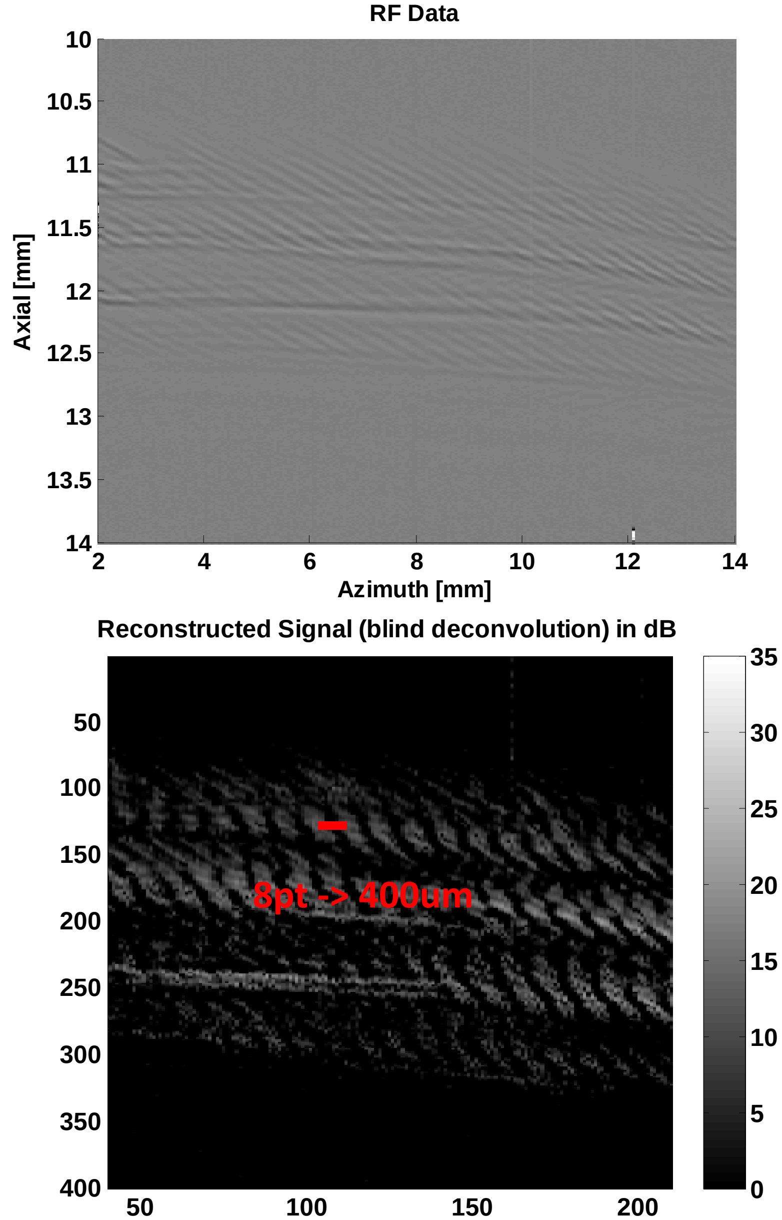


Fig.2 (Top) Photoacoustic image of the phantom using RF data. (Bottom) Reconstructed photoacoustic image of the phantom.

Anisotropy of photoacoustic signal from fibrous tissues: *in vitro* measurements

- Goal: Investigate ultrasonic (US) and photoacoustic (PA) scattering in fibrous tissues by experiments.

- Hypothesis:
  - US wave exhibits coherent scattering from each individual scatterer; whereas, PA wave are consider to have incoherent scattering.
  - High frequencies showed more prominent anisotropic scattering as compared with low frequencies.
  - Signal intensity decrement for photoacoustic waves was less than that of ultrasonic waves.

- Representative figures:

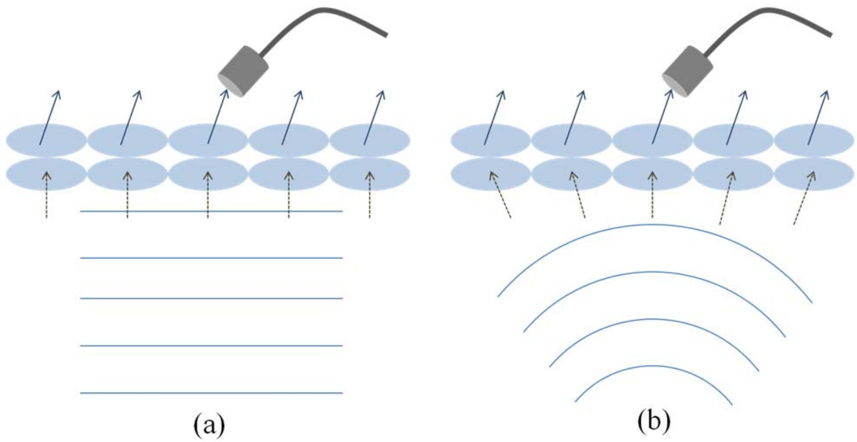


Fig.1 Wave propagation from different incident source geometry: (A) ultrasound case (B) Photoacoustic case

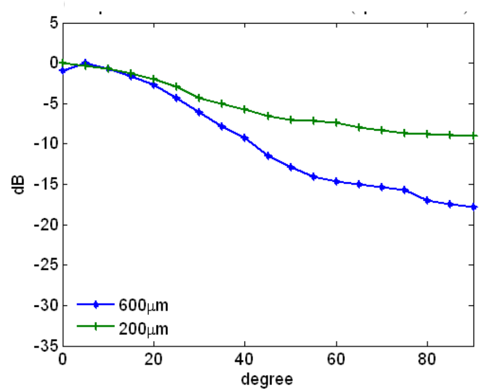


Fig.2 Photoacoustic integrated scatter using optical fiber of 200 μm/600μm diameter

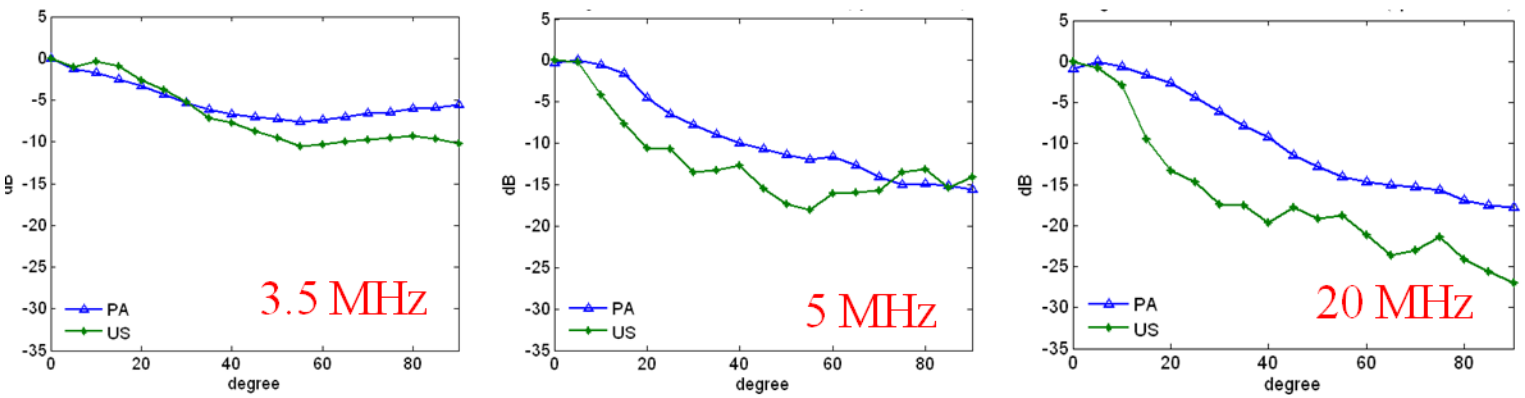
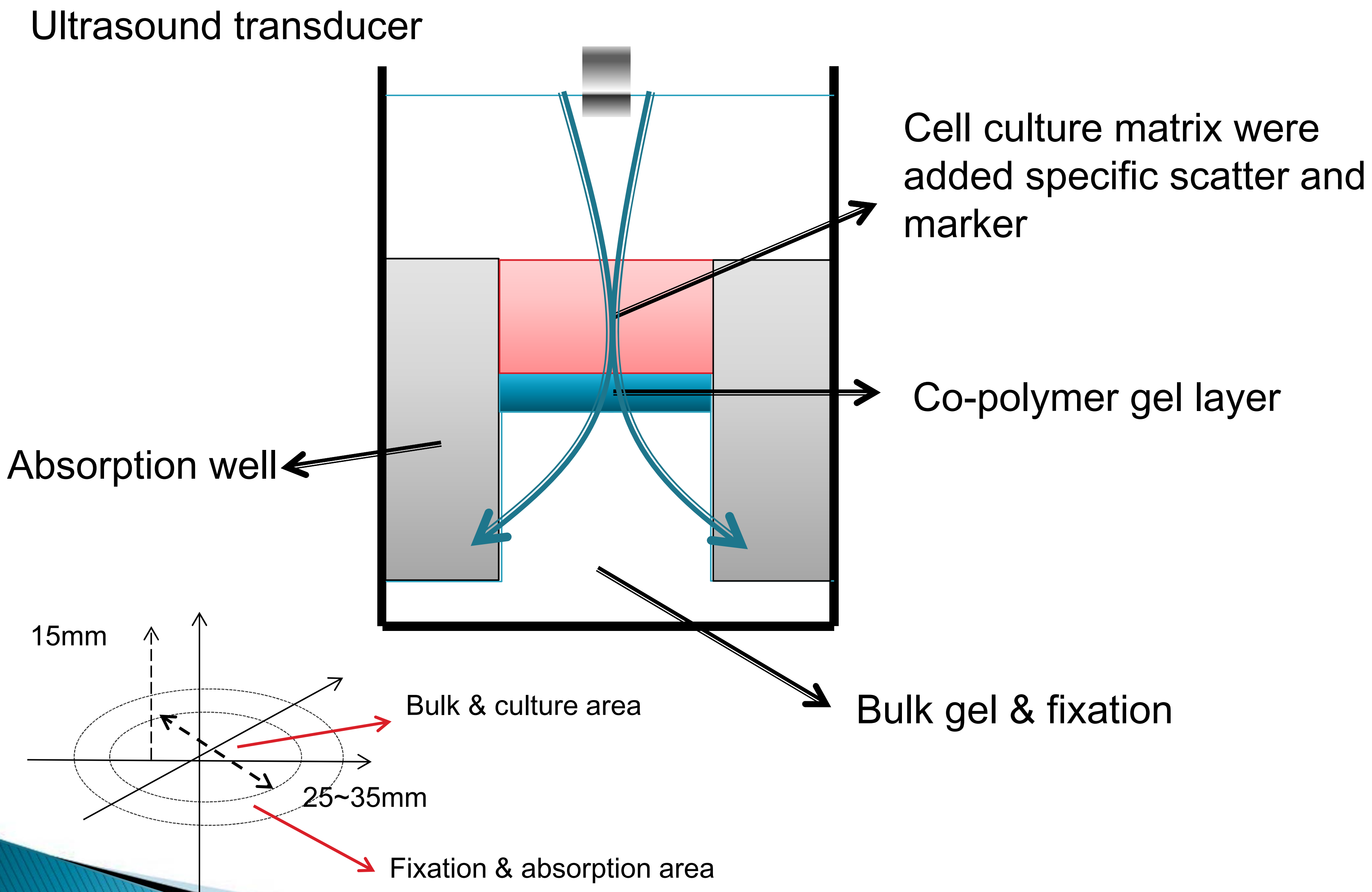


Fig.3 Ultrasound and photoacoustic integrated scatter versus detection angle using transducers with different center frequencies

Design 3D cell culture system with PA/US image analysis

- Goal: Design and fabricate 3D matrix for cell culture and US/PA imaging, this matrix were added scatter and marker to track cell migration and ECM remodeling.

- Hypothesis: Cell on the basis of different matrix property will secrete specific molecule and change morphology to remodel matrix, utilize scatter and marker for imaging that can apply this systems to research cell behavior.


Ultrasound transducer
Cell culture matrix were added specific scatter and marker
Co-polymer gel layer
Absorption well
Bulk gel & fixation
15mm
Bulk & culture area
25~35mm
Fixation & absorption area