Realtime plane-wave software beamforming with an iPhone

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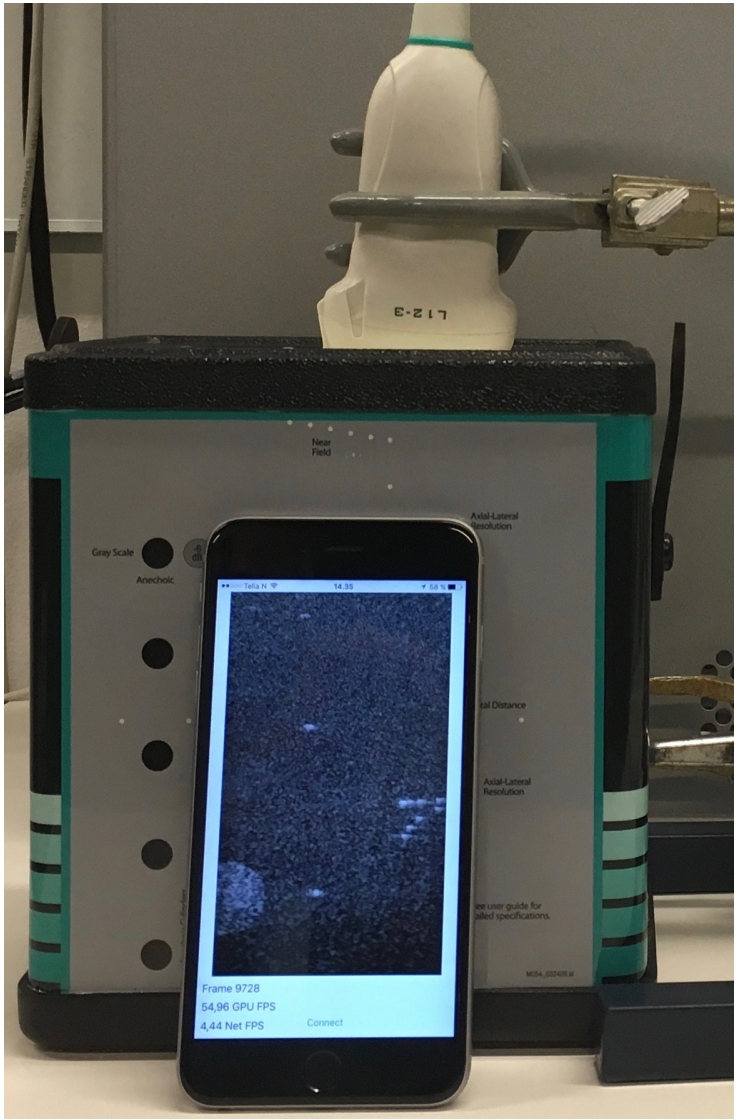
Objective

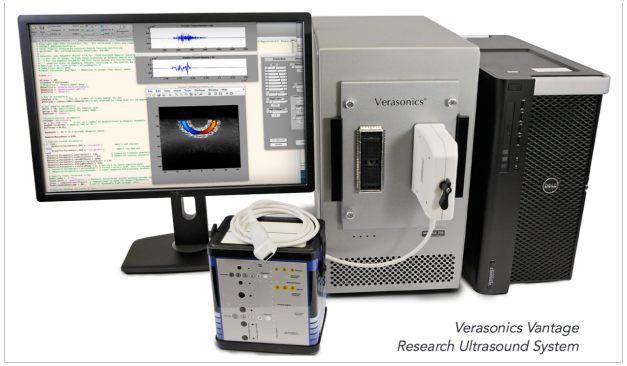
- Investigate the feasibility for an iPhone to beamform plane-wave images with the channel data wirelessly transmitted to the device.

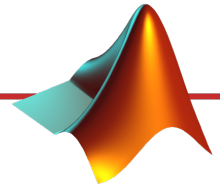
Why is this interesting?

- Proof of concept that the probe in a handheld system only needs hardware to acquire and transmit the channel data, while the beamforming can be done in software on commercially available devices.



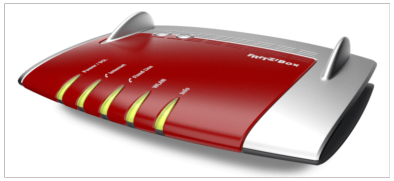
Functional diagram

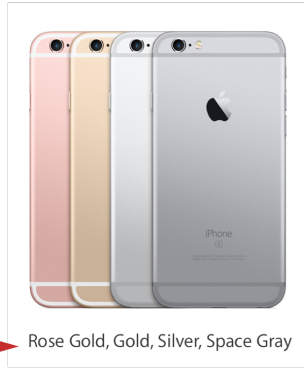




python™

Channel Data





Not to scale

Recording and transmitting the channel data

Recording data on the Verasonics Vantage Scanner

- L12-3v 192-element linear array.
  - Only using 128 elements
  - Transmitting one plane wave 7.8 MHz recording a 45.8 mm deep image.
  - The data is IQ sampled.
  - Total of 128 x 512 IQ samples

Transmitting the data

- The data is JSON-serialized and POST'd with webwrite()
- Python script takes POST and broadcasts to all connected WebSockets

A simple serialization format

```
{
    "identifier"   : x,
    "channel_data" : [[channel_1_samples],
                      [channel_2_samples],
                      [...],
                      [channel_n_samples]]
}
```

Uncompressed: ~400 kB, Compressed: ~40kB

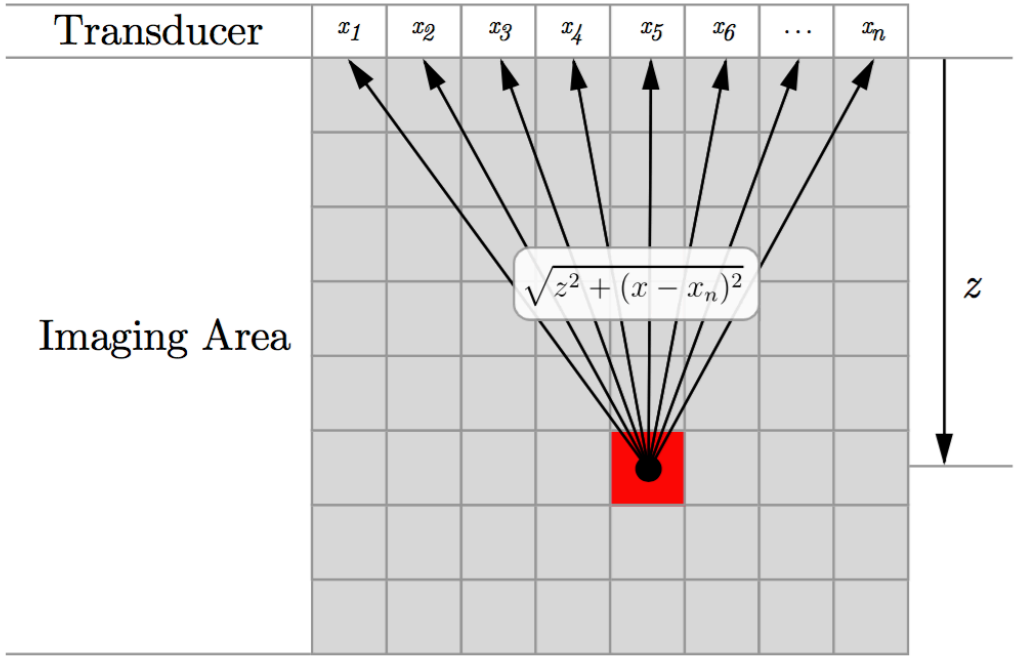
Receiving and beamforming the data on the iPhone - Overview

1. Data arrives on WebSocket
2. Decompression if applicable
3. Deserialization to a first class object
4. Perform delay calcuations (one-time)
5. malloc (one-time) region of memory to hold channel data
6. memcpy channel data to memory
7. Perform channel data computations
8. Convert results into a UIImage
9. Display resulting image

Pixel-based beamforming

1. Calculation of delays

$$\tau(z, x, x_n) = (z + \sqrt{z^2 + (x - x_n)^2})/c.$$



Pixel-based beamforming (PBB)

2. Delay-and-sum calculation

$$I_{DAS}[z,x] = \sum_{m=0}^{M-1} w_m y_m[z,x]$$

3. Take decibel value of envelope

$$I_{\mathrm{dB}} = 20 \cdot \log_{10}(|I_{\mathrm{DAS}}|)$$

How is PBB implemented?

- Swift, Objective-C, and Metal
- Roughly two steps
  1. Pre-calculate and store the delays for every pixel in the defined pixel grid in memory.
  2. Channel data processing
     - One thread per pixel
     - Each thread then delays by linear interpolation and sums the contribution from each channel recorded
     - The amplitude is detected, and the log compression is done

Results

The iPhone can beamform a plane wave image

- GPU ~55 FPS when the channel data is stored on the phone
- Network ~5 FPS when the channel data is wirelessly transmitted

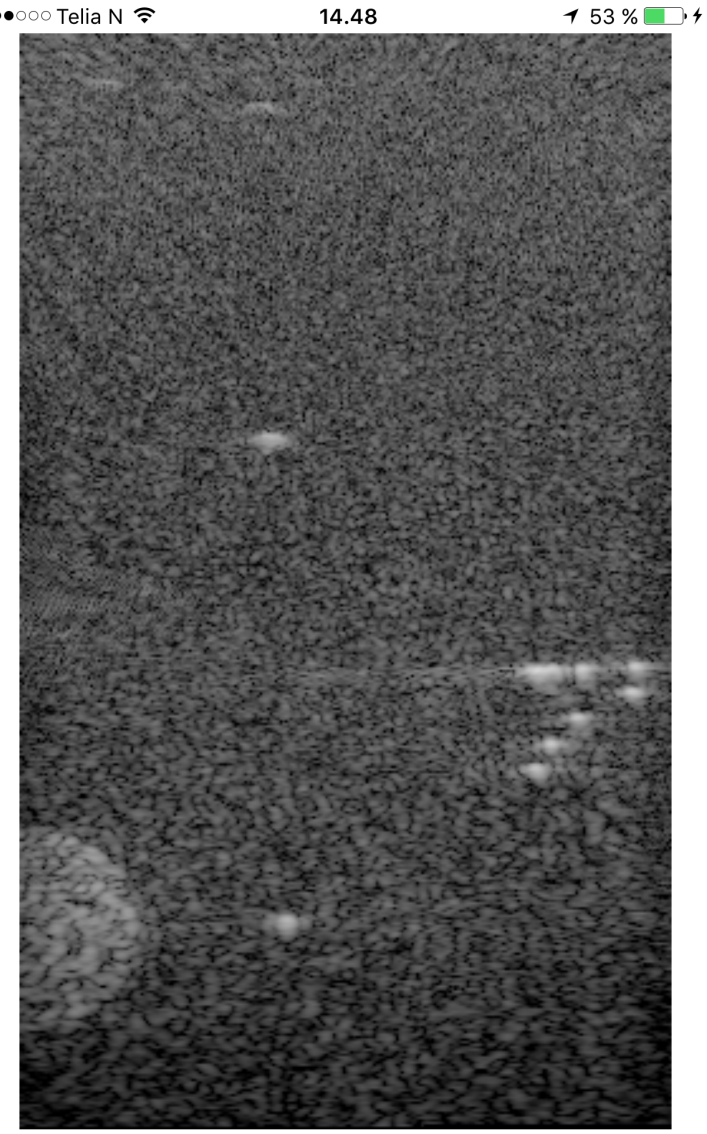
	Net FPS	GPU FPS
129x217px λ	4.5 (σ=0.5)	142.0 (σ=5.9)
258x434px $\lambda/2$	4.5 (σ=0.2)	55.5 (σ=0.7)
375x632px $\lambda/3$	4.9 (σ=3.3)	29.4 (σ=1.1)

Results

Image quality

As expected from single plane wave image

- Visible side-lobes
- Fixed aperture leads to a noisy near field



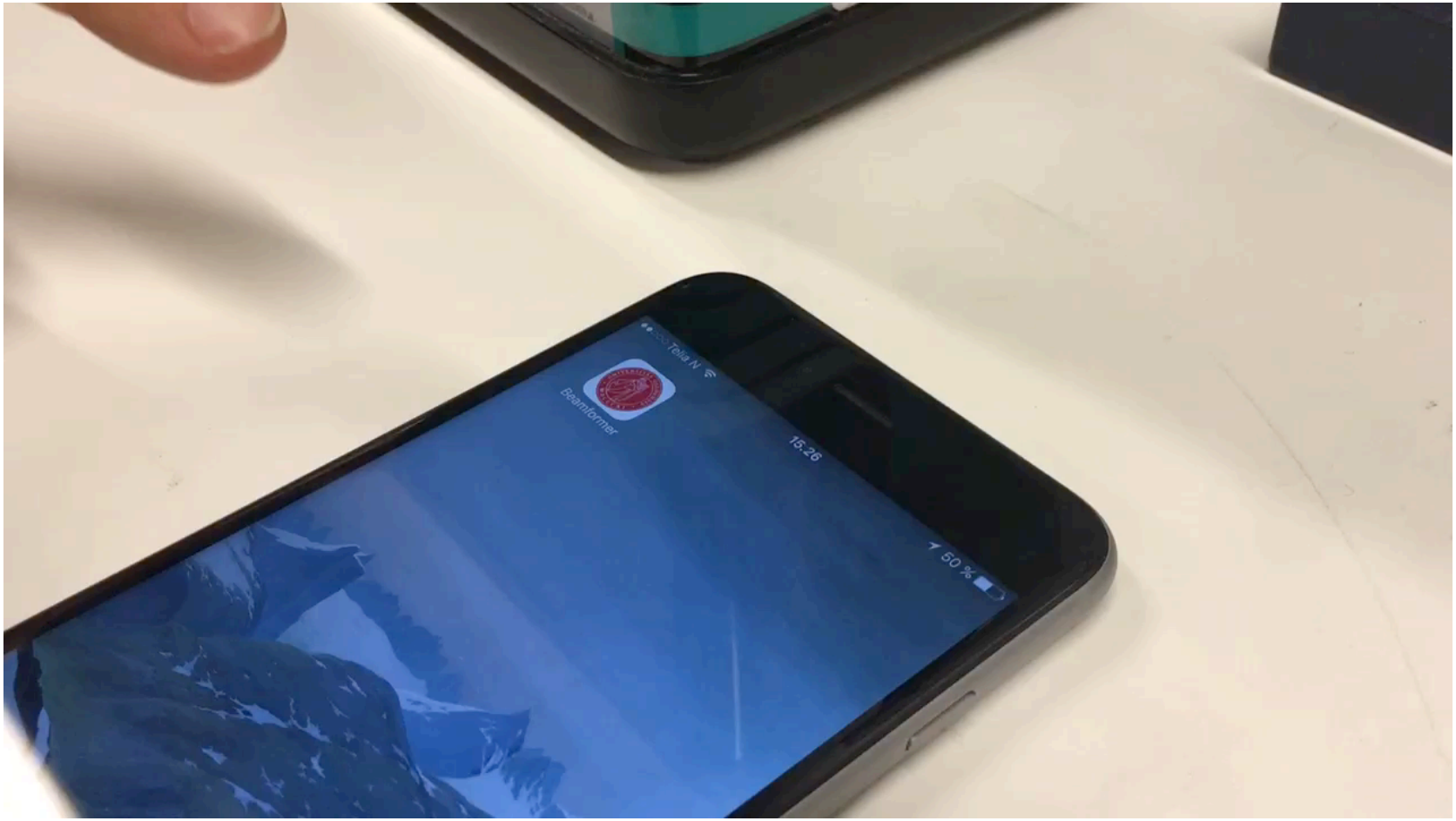
Frame 13398

55,51 GPU FPS

4,43 Net FPS

Connect

Demonstration



Discussion

- The bottleneck is the serialization
  - We are got to switch to a binary protocol
    - Apache Thrift
    - Google Protocol Buffers
- We are currently working with the implementation of compounded plane wave imaging to improve the image quality
  - Adding dynamic aperture
  - Multiple angle compounding

Conclusions

- We have shown that realtime plane-wave ultrasound imaging with an iPhone is feasible when processing wirelessly streamed channel data using a Verasonics Vantage ultrasound scanner and iPhone 6s at ~5 FPS. The GPU processing frame rate is much higher measured at 55 FPS for a 25.5 mm wide and 45.5 mm deep image using $\lambda/2$ pixel spacing and can be viewed as the upper-bound of our current implementation.