Redefining Neuroimaging Standard of Care: An Implantable Ultrasound for Real-Time Diagnosis of Brain Diseases

Team

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Goal: An Implantable Ultrasound Device for Real-Time Diagnosis of Brain Diseases

- **To** Develop the first implantable ultrasound device for long-term post-neurosurgical monitoring.
- The primary aim is to monitor the potential regrowth of brain tumor in real-time using an app. The ultrasound smart device will also assist physicians to monitor bleeding, cyst, growing tumor, etc., of the over 11 million patients that are affected annually with brain diseases.

An Implantable Wireless Ultrasound Device for Real-Time Diagnosis of Brain Diseases

Background

- Currently, the standard of care for patients who have undergone neurosurgery is to get periodic MRI scans (approximately every 3 months)
  - Average cost of the scan is $3000
  - Ultrasound (US) works with a lower resolution but insightful information can be deciphered
  - A cranial implant is needed after neurosurgery so there is precedent for an implantable device (shunt management system created by Dr. Gordon)
  - Integration of an US system would allow for more imaging to determine adverse events in a more expedient time frame (< 1 month)

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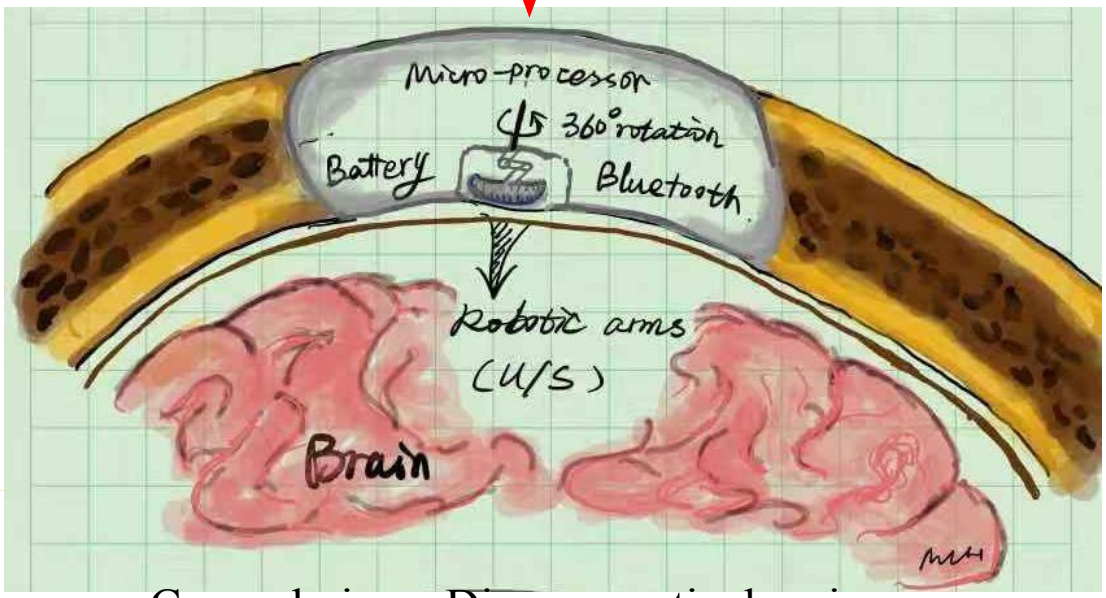
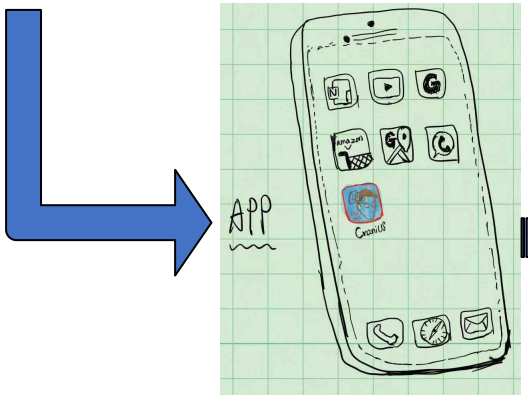
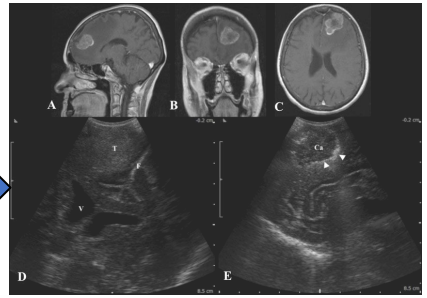
- Ultrasound probe
- Bluetooth
- Battery
- Micro-processor



Coronal view : Diagrammatic drawing





Source: Dr. Ma

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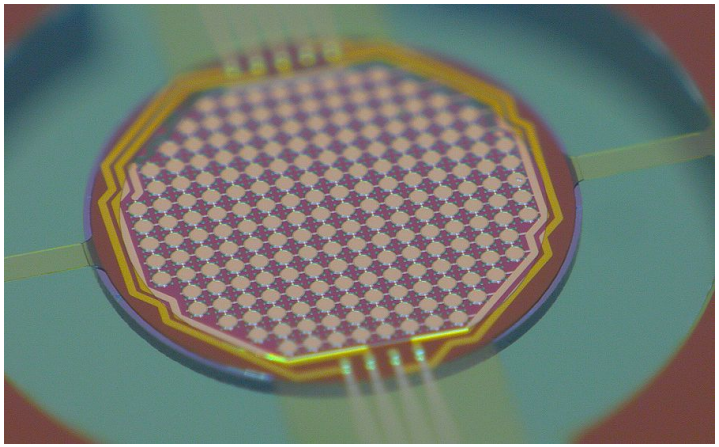
Proposed Approach: Capacitive Micromachined Ultrasound Transducer

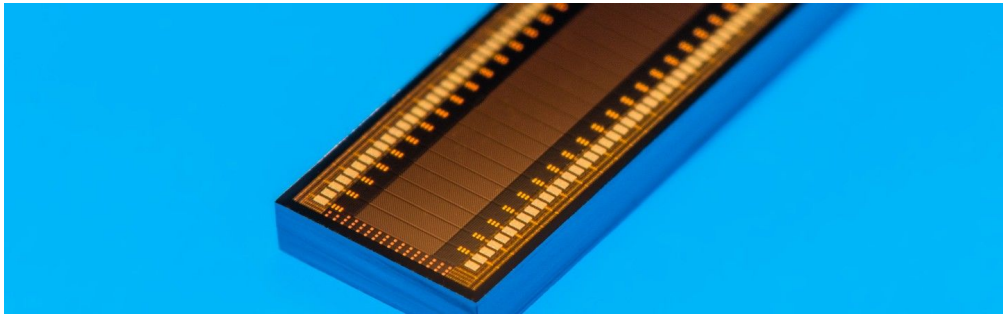
Ultrasound (Traditional)

- produced sound waves by utilizing piezoelectric crystal technology
- high production cost

CMUT

- silicon chips that convert voltage to resonance
- customizable with electronics
- small in size
- can be mass produced
- low cost





Source: Philips,Fraunhofer IPMS

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Miniature ultrasound ring array transducers for transcranial ultrasound neuromodulation of freely-moving small animals

Hyunggug Kim [a], Seongyeon Kim [a], Nam Suk Sim [b], Cristina Pasquinelli [c, d], Axel Thielscher [c, d], Jeong Ho Lee [b], Hyunjoo J. Lee [a, *]

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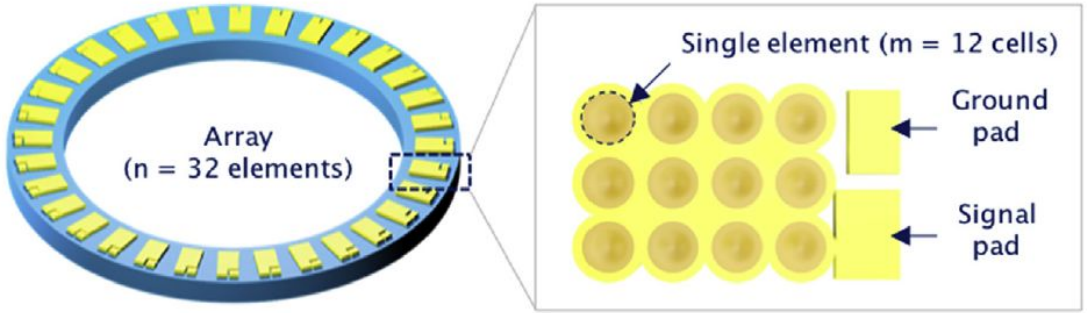
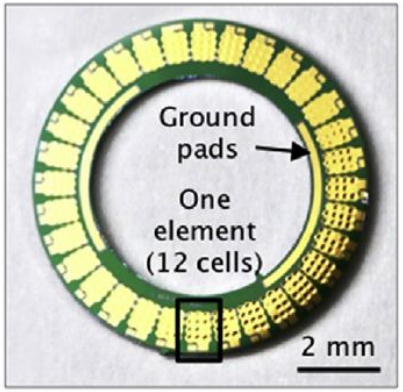
[d] Department of Electrical Engineering, Technical University of Denmark, DK-2800, Kgs. Lyngby, Denmark

A

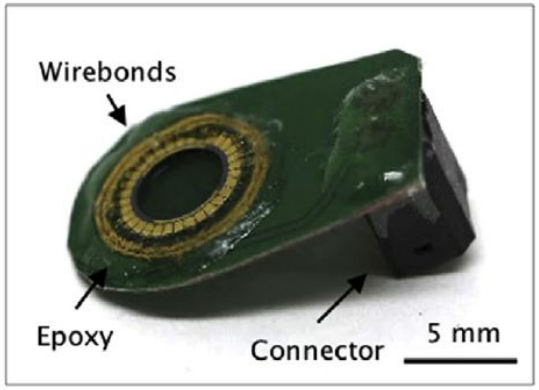


B

OD: 8.1mm ID: 5.2mm



C



Materials and methods

We designed and fabricated a ring array with an outer diameter of 8.1 mm and an inner diameter of 5.2 mm to generate a focal point at approximately 2.3 mm from the device with an immersion resonant frequency of 183 kHz (Fig. 1A, B, S1). Ring array was chosen because of the following advantages: natural focus at the center (Figure S2), larger aperture while minimizing localized skull heating, and extra room in the middle for integration with other devices. The ring array is composed of 32 elements, and each element is composed of 12 circular resonating plates (or cells) connected in parallel [24,25]. The weights of the ring array and fully-packaged array with a custom-designed printed circuit board (PCB) were 0.035 g and 0.73 g, respectively (Fig. 1C). For further information, see Supplementary Methods.

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Original Deliverables

- **Minimum**: Mock ultrasound image communication from a microprocessor with stored images to mobile app
- **Expected:** Mock ultrasound image communication and macro scale integration (images obtained from an ultrasound system to the microprocessor and mobile app)
- **Maximum**:Miniature patentable ultrasound device with mobile app communication

Management

- Communication with the medicine delivery team regarding electronics constraints, wireless functionality, and wireless charging via weekly lab meetings
- Weekly lab meetings with Dr. Gordon, Dr. Armand, Dr. Scott
- Additional weekly meeting with Dr. Ma
- Meetings after class within the team

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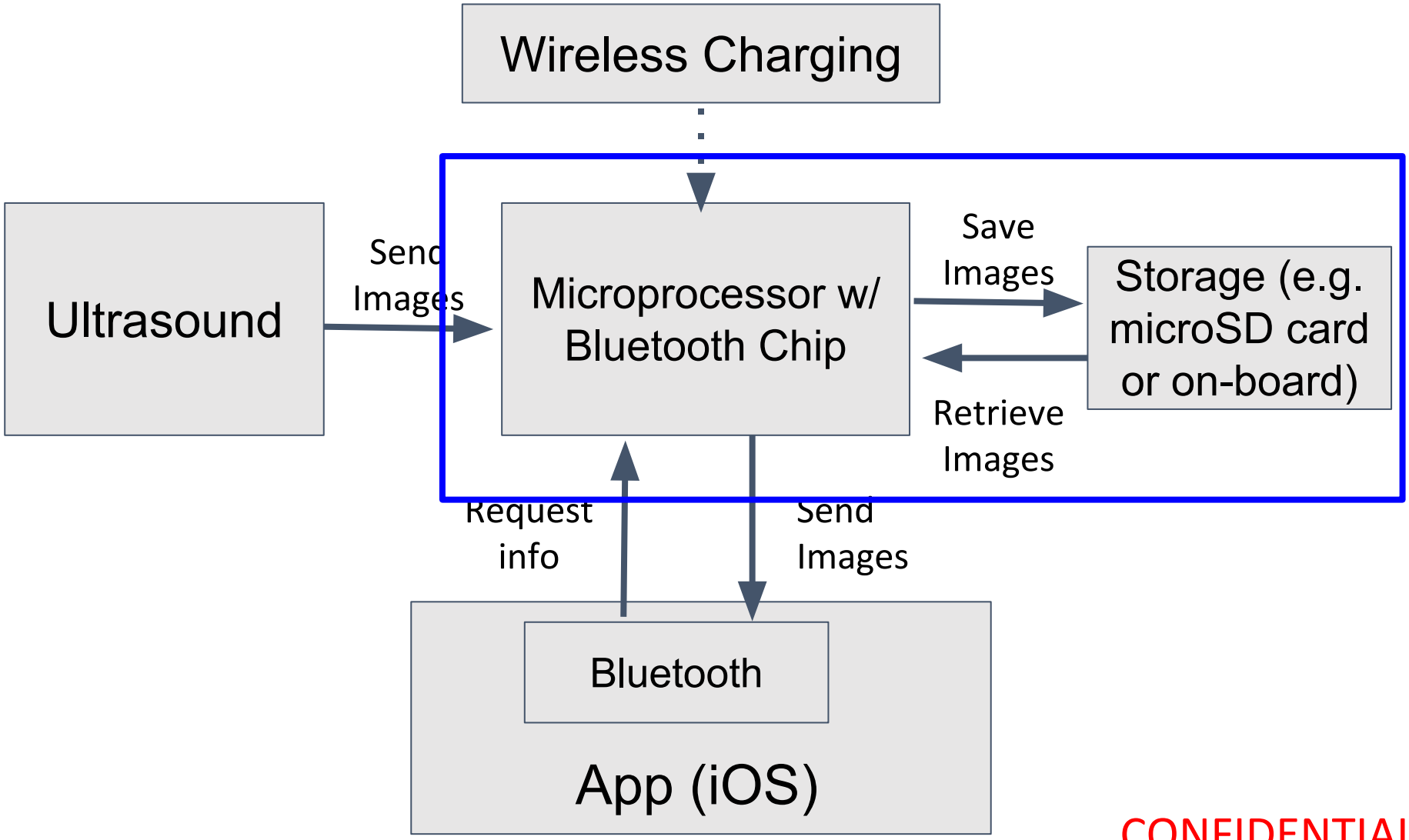

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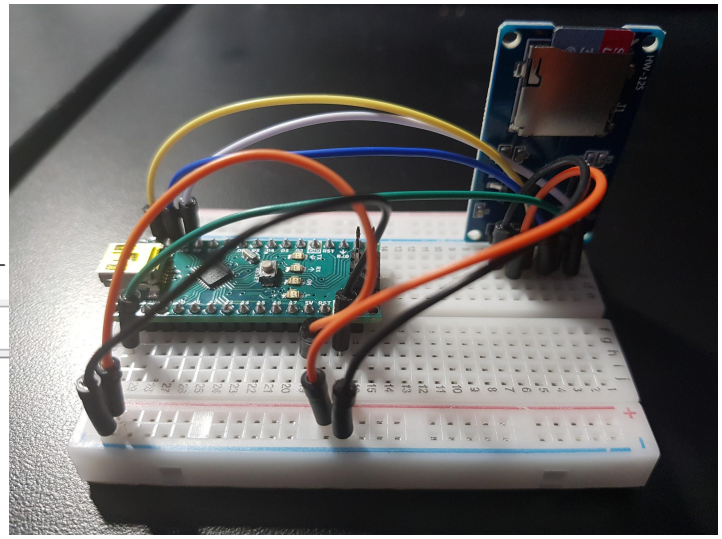
Arduino -- SD Card Communication



COM6

```
Initialization SD Card...initialization done.

Enter function (read/write)...write

Enter file name...testdata.txt

208     40      167     180     112     70      192     215     90      19
231     248     9       8       97      174     65      65      212     13
32      245     217     70      195     167     129     208     149     135
233     124     239     11      203     41      178     62      140     199
161     204     173     24      47      30      228     237     234     239
24      36      193     210     125     127     245     89      73      33
71      107     190     177     114     245     140     50      193     145
140     234     100     81      165     87      35      64      192     120
245     202     167     243     181     149     38      157     97      3
247     245     43      8       193     57      65      121     145     86
Data Entry Complete. Close Serial Monitor
```

Autoscroll | Show timestamp | Newline | 9600 baud | Clear output

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Arduino -- SD Card Communication

TESTDATA - Notepad

File Edit Format View Help

208	40	167	180	112	70	192	215	90	19
231	248	9	8	97	174	65	65	212	13
32	245	217	70	195	167	129	208	149	135
233	124	239	11	203	41	178	62	140	199
161	204	173	24	47	30	228	237	234	239
24	36	193	210	125	127	245	89	73	33
71	107	190	177	114	245	140	50	193	145
140	234	100	81	165	87	35	64	192	120
245	202	167	243	181	149	38	157	97	3
247	245	43	8	193	57	65	121	145	86

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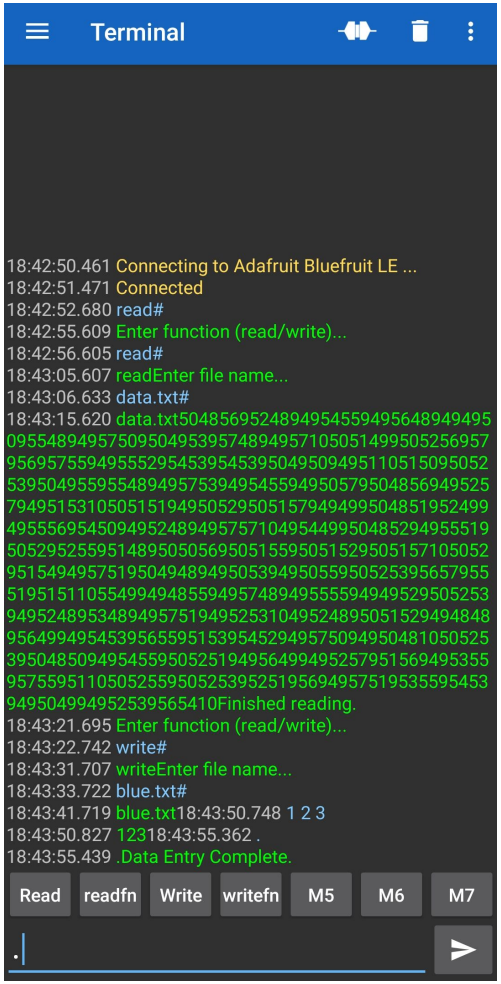
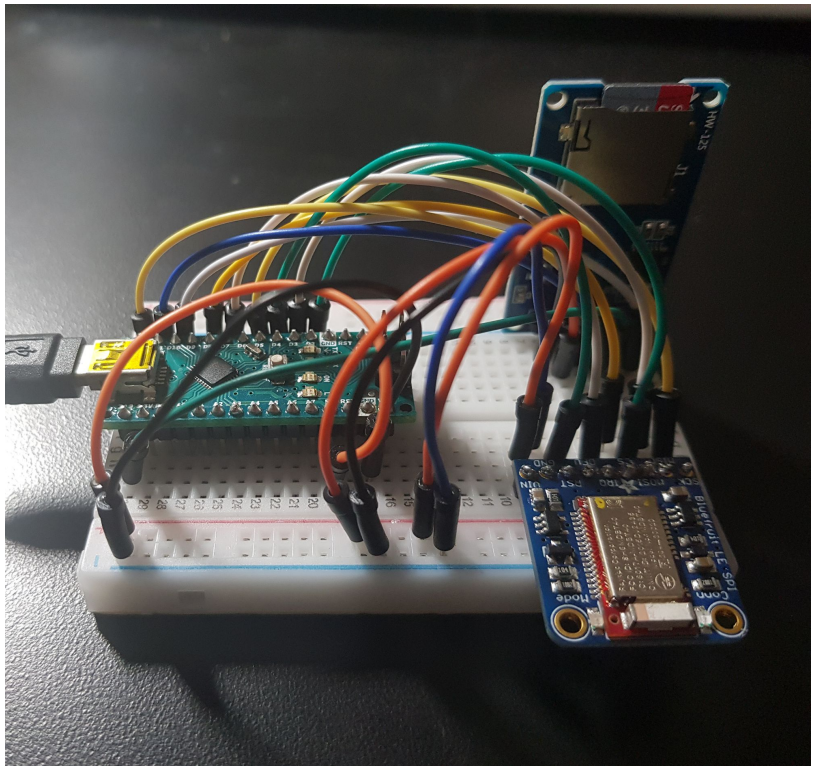
Bluetooth -- SD Card Communication





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New Deliverables

- **Minimum**: Mock ultrasound image communication from a microprocessor with stored images to mobile app
- **Expected:** Ultrasound image communication from Clarius Probe to mobile app
- **Maximum**:Ultrasound raw data communication from either Clarius or stored data to mobile app that forms beamforming to produce the ultrasound image

Management

- Communication with the medicine delivery team regarding electronics constraints, wireless functionality, and wireless charging via weekly lab meetings
- Weekly lab meetings with Dr. Gordon, Dr. Armand, Dr. Scott
- Additional weekly meeting with Dr. Ma
- Meetings after class within the team

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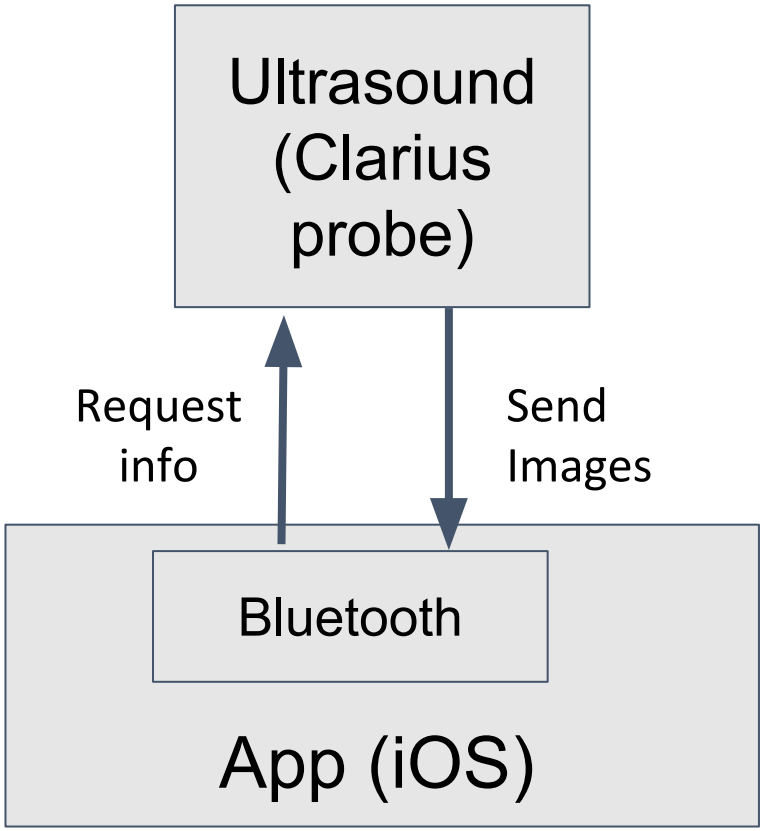
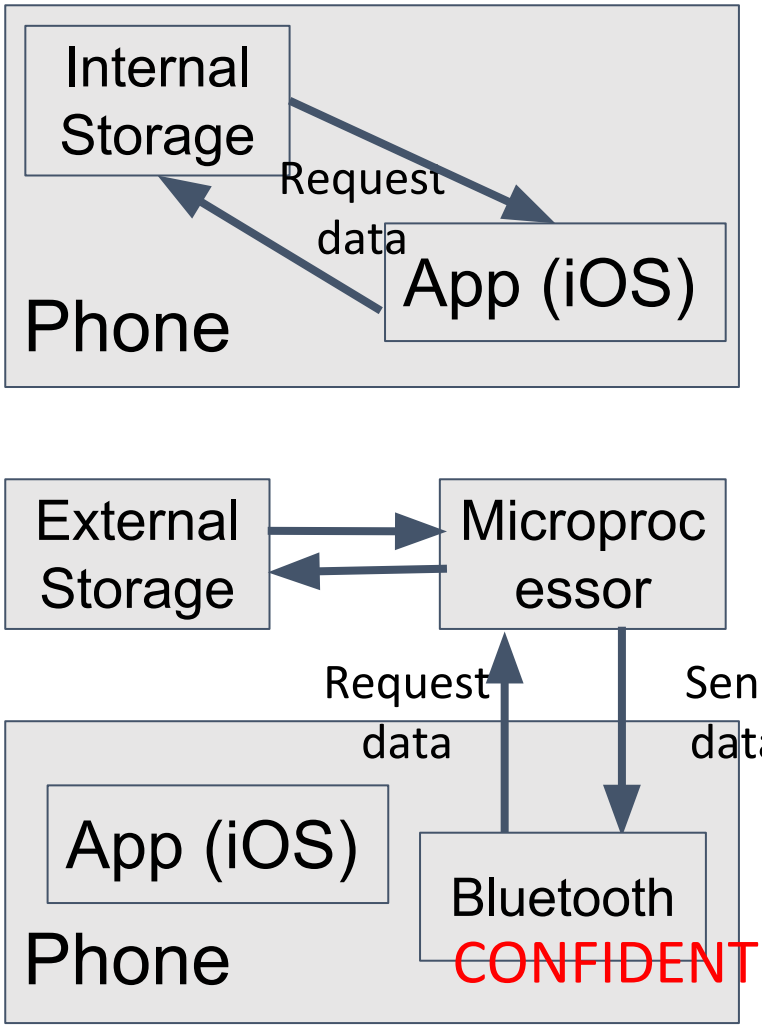
Expected



Maximum



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Dependencies

Item	Proposed Solution	Alternative	Date Needed (Status)
Ultrasound	Clarius Probe	N/A	Resolved
Arduino	Order or use our own	Order ourselves	Resolved
Bluetooth Chip	Order through Dr. Gordon	Order ourselves	Resolved
SD Card + Module	Order through Dr. Gordon	Order ourselves	Resolved
XCode			Resolved
iOS Phone	Use our own phones	Use XCode Simulator	Resolved
Computer	Personal PCs	Family member's PC	Resolved
Data Storage	Github	Ext Hard Drive	Resolved

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Project Plan

Dates	Goals	Status
4/3	• Have Matlab simulation/beamforming code finalized • Preliminary UI written, displayed in XCode Simulator	Done Done
4/10	• Display Clarius image in our app • Compile Matlab beamforming code into C • CSV file communication (bluetooth) from Arduino to app	In progress Done In progress
4/17	• Be able to beamform locally saved data	In progress
4/24	• Be able to beamform bluetooth transmitted saved data	In progress
5/1	• Preliminary draft of paper	Not started
5/8	• Final draft of paper	Not started

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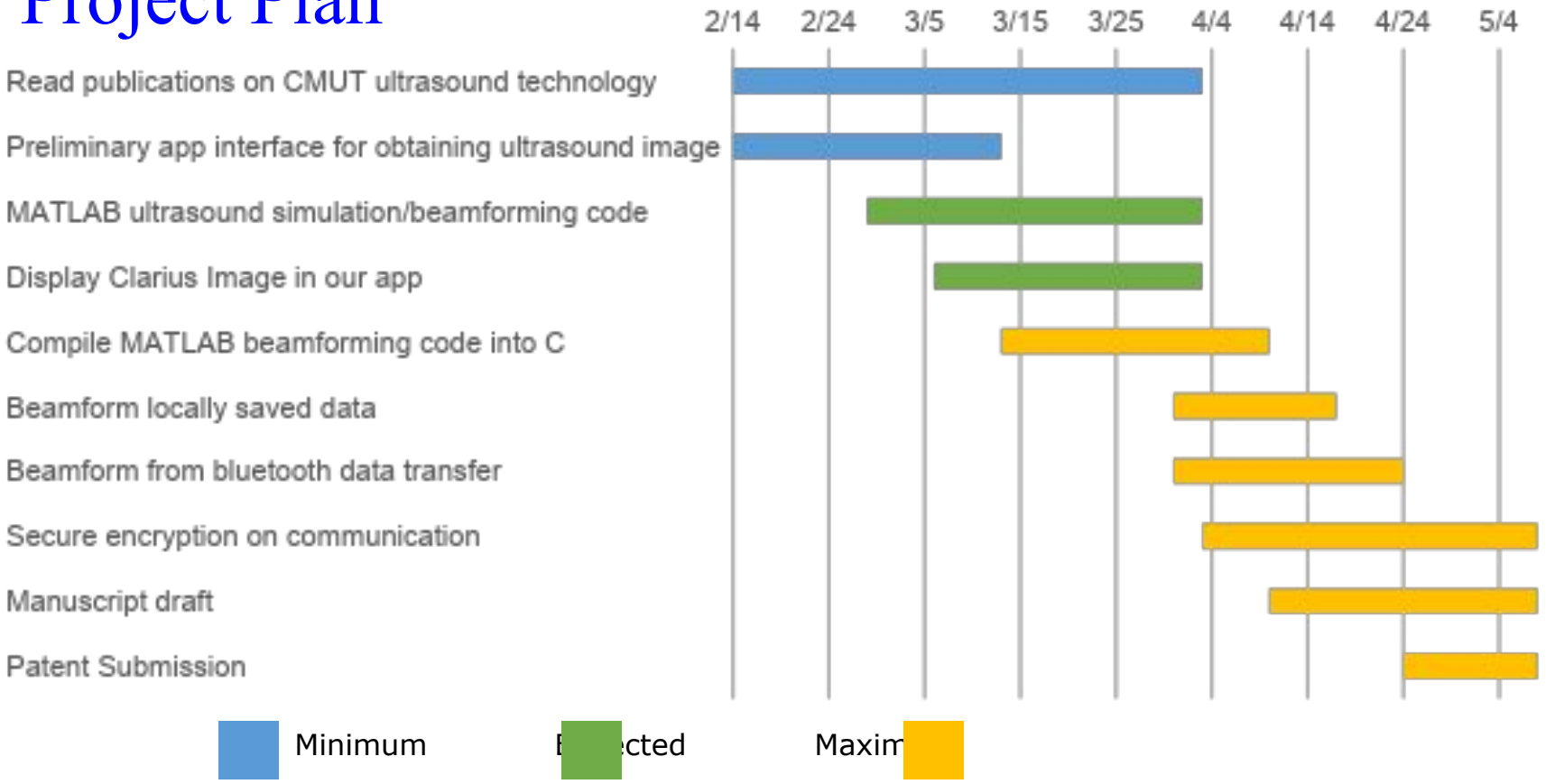
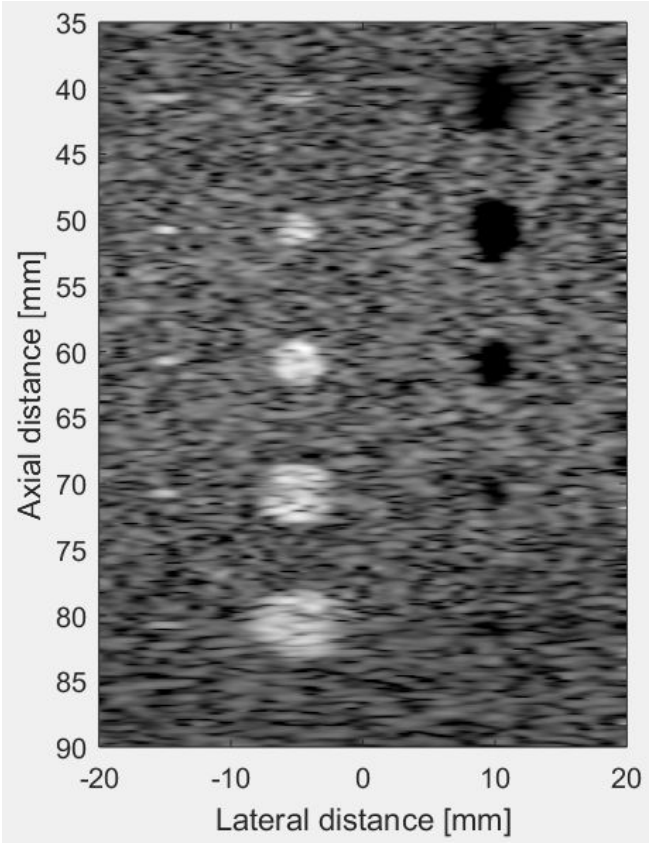
Project Plan



Beamforming Updates

- Installed/configured the Field II library for Matlab beamforming and simulation
- Ran example provided by Field II successfully (able to simulate a cyst phantom, save the data, and reconstruct the image using saved data)
  - Simulation takes time (~30 min) but creating the image takes **3s**
- Compiled Matlab code in C



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Documentation

Beamforming [Matlab]

- [positions, amp] = cyst_phantom(N)
  - N: number of scatterers
  - Positions: position of scatters
  - Amp: amplitude of scatters
  - Used to create the model of the cyst phantom
    - five point targets
    - 6, 5, 4, 3, 2 mm diameter water filled cysts
    - 6, 5, 4, 3, 2 mm diameter high scattering regions
  - All scatterers are situated in a box of (x,y,z)=(50,10,60) mm and the box starts 30 mm from the transducer surface.
- simulation()
  - Script that runs the entire simulation
    - Initializes the Field II environment
    - Calls cyst_phantom to create the model of the cyst phantom
    - Simulation of the ultrasound probe
    - Saves the data
  - Data is saved in a file within the same directory names 'rf_data.mat'
    - Saved variables:
      - rf_data_all: response data
      - tstart_all: start time
- make_image()
  - Script that creates the beamformed image
    - Reads in the file 'rf_data.mat'
    - Performs computations
    - Display the image
  - Image is not saved [**TODO**: save the image in a variable if helps in compiling with C]
- Note: all scripts are dependent on the Field II Matlab library (available for free) located 1 level above these scripts
  - Change the directory in line 17 of simulation() if Field II directory is located elsewhere

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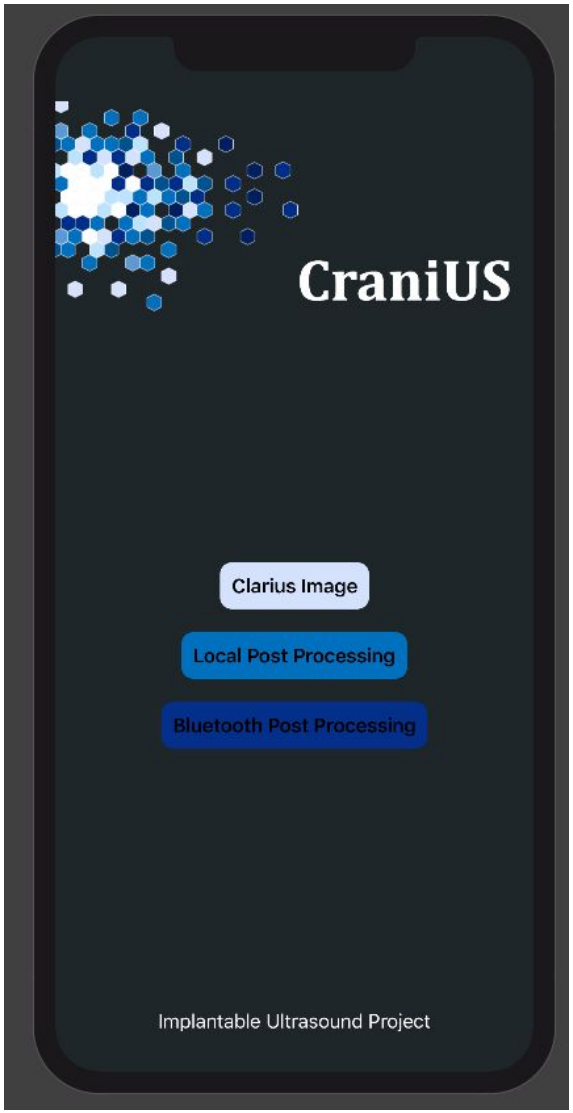
App Updates

- Wrote preliminary UI
- Able to deploy the app onto a mobile phone for testing



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