iPhone Ultrasound

Senior Design Project Proposal

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1. **Introduction**

   a. The motivation of this project is to create a low-cost, portable A-scan biometric ultrasound circuit driven by an iPhone 4S. This would provide an inexpensive ultrasound alternative with a more user-friendly interface compared to existing optical ultrasound solutions.

   b. **Objectives:** The goal of our project is to implement a system that can perform 1-dimensional biometric scans that ophthalmologists can use to measure the axial lengths of eyeball components. These measurements of the eye are used to calculate intraocular lens (IOL) power for cataract surgeries. Ultrasound transducers typically operate at 10MHz, since the short distances in the eyeball require high resolution. While there are handheld ultrasound probes available, they all use processor/video/input hardware created specifically for that device - driving up its cost while having a poor user interface.

      In addition, many third-world countries lack structured land-line communication networks, making the sharing of this kind of medical information a heavy task. A system of sharing this information over modern, conventional wireless networks may aid in the health-care of ailing citizens.

      Our project aims to alleviate these problems by improving upon the user interface of existing devices, driving down costs with the use of hardware many doctors already own (the iPhone 4S), and securely sending eye scan results over established cellular networks.

      Benefits:

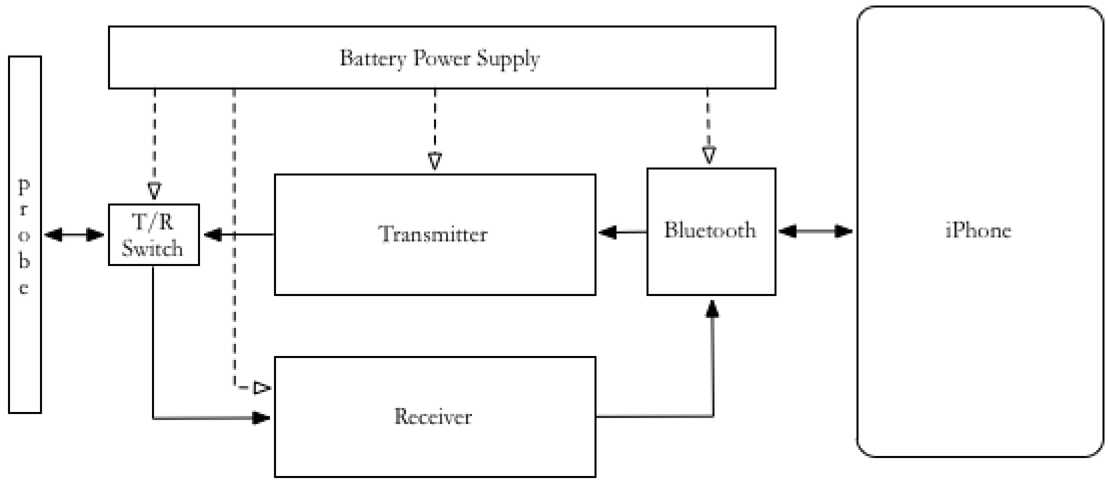
      - Lower medical device costs with the use of existing hardware
      - Highly portable form factor
      - Immediate/live ultrasound measurements
      - Accurate Axial Eye Length (AEL) measurements

      Features:

      - 10 MHz single-element ultrasonic transducer probe
      - Wireless transmission of A-scan data to iPhone 4S over Bluetooth Low Energy standard
      - Provides user with one echogram per second
      - User-friendly interface on 3.5” iPhone 4S LCD display with touch user interface
      - Choice of contact or immersion measurement
      - Numeric values displayed for anterior chamber depth, lens thickness, vitreous length, and AEL with 0.2 mm resolution
      - Integrated IOL power calculator
      - Storage of up to 500 echograms for review and critiquing
      - Ability to send echogram images over MMS or e-mail

2. **Design**

a. **Block Diagram:**



b. **Block Descriptions:**

- **Ultrasound Probe:**
  The ophthalmic ultrasound transducer probe is responsible for transmitting and receiving ultrasonic pulses by means of a single piezoelectric element that operates at 10MHz. In the transmission phase, a high-voltage pulse is sent to the Probe, which relays an ultrasonic pulse out of the Probe's tip. As the Probe receives the echoes from that pulse, it relays low-voltage pulses back to the circuit.

- **T/R Switch:**
  The Transmit/Receive Switch controls the operating modes for the Ultrasound probe and signals leading to/from it. This prevents interference between the high voltage pulses being sent to the probe transducer and the lower amplitude echoes being returned from the eye. This also protects the low noise amplifier in the Receiver from the higher voltage signals coming from the Transmitter.

- **Transmitter:**
  The Transmitter circuit is comprised of two main components: the Transmit Beamformer and Transmit Pulser. The Transmit Beamformer accepts transmission control signals from the iPhone via the Bluetooth module, and a 10 MHz signal is generated. This pulse is sent to the Transmit Pulser which "windows" a short, high-voltage pulse through the T/R Switch.

- **Receiver:**
  The Receiver circuit preprocesses signals received from the Ultrasound Probe into more meaningful ones for AEL measurement at the back end of our device. Because received signals are attenuated as they travel through eye tissues, this circuit tailors the gain of the amplifiers to compensate for these losses over time through Time-Gain Compensation. This circuit also converts the amplified analog signal to digitized data that is sent over the bluetooth module.

- **Bluetooth:**
  The bluetooth module acts as the communication interface between the probe and the iPhone. It communicates with three components: the iPhone, Transmitter, and Receiver. Commands to initiate and stop scans are wirelessly received from the iPhone and passed as control logic inputs to the Transmitter. Pre-processed and digitized data from the Receiver are received and wirelessly transmitted to the iPhone.

The bluetooth module also sends signals to status LED indicators.

- **iPhone 4S:**
  The iPhone serves as the graphical user interface, displaying scan results and accepting user input commands. The user can initiate and stop a scan from the phone, with a live graph of incoming ultrasound measurements available while the scan is in progress. Between scans, the user can adjust sound velocity parameters for different eye conditions, perform IOL calculations, save the last scan, or send a scan image via email or MMS.

- **Battery Power Supply:**
  A 9V Lithium-Ion battery will be used to supply power to the chips on the device's front end circuitry (T/R switch, Transmitter, Receiver, and Bluetooth Chip). Voltage regulators will be implemented to satisfy individual chips' requirements.

c. **Performance Requirements:**

- Measurement accuracy within 0.2mm for anterior chamber depth, lens depth, vitreous length, and axial eye length
- Transmitted Pulse frequency of 9.5-10.5 MHz
- Provide at least one A-scan image to be displayed by the iPhone per second
- Low power consumption to operate on one 9V battery

3. **Verification**

a. **Testing Procedure:**

- Two polystyrene test blocks will be used to verify the accuracy of our device. Each will be of known thickness. One will have a thickness equal to a typical anterior chamber depth. The other will have a thickness equal to a typical axial eye length. These correspond to the smallest and largest length measurements to be calculated. Upon performing an A-scan with our device, each calculated depth should be within 0.2mm of the actual thickness.
- Prior to entering the transducer probe, capture the transmission pulse with an oscilloscope and measure its period. If the corresponding frequency (its inverse) is between 9.5 and 10.5 MHz, then our transmission frequency has met our requirement.
- View XCode data log to verify that a full scan is transmitted to the iPhone per second. For an observational approach, count the number of new frames for a 60 second period. If the scan display was updated at least 60 times, then our requirement has been met.
- Place an ammeter in series between the battery and its lead to the power circuitry. Operate the device for 60 seconds, taking note of the average current pulled. Use that information to extrapolate the amount of energy pulled in one hour. If that energy is less than the battery's total capacity, then the device can successfully operate for a full hour on a 9V battery.

b. **Tolerance Analysis:**

- As the Bluetooth chip can only transmit up to 8 kB/s, and each unfiltered scan will require approximately 4 kB of data, we will send one scan per second to be displayed on the iPhone. The wireless connection between the iPhone and Bluetooth chip must remain stable in order to ensure that scans displayed on the screen are updated at the expected frequency of 1 Hz. We will test for the operable range of the iPhone from the probe circuitry that will ensure a stable connection with no loss of data packets. By sending several scans to the iPhone at distances increasing from 0 m by 0.5 m, we will determine the maximum range radius and document this in our final report. We will test for this range with no obstacles between the devices and with one wall between them.

4. **Cost and Schedule**

a. **LABOR:**

Name	Hourly Rate	x 2.5	Hours*	Total
Jonathan	$40/hr	$100/hr	240 hrs	$24,000
Adam	$40/hr	$100/hr	240 hrs	$24,000
Dean	$40/hr	$100/hr	240 hrs	$24,000
			LABOR TOTAL:	$72,200

*20 hrs/wk x 12 wks = 240 total hours per person

b. **PARTS:**

Part Name	Qty.	Cost	Total
iPhone 4S (without contract)	1	$700	$700
Storz Ultrasound Transducer Probe	1	$700	$700
TI CC2450 (Low Power Bluetooth Chip)	1	$2	$2
TI AFE5801 (Ultrasound Analog Front End Chip)	1	$40	$40
TI LM96530 (High Voltage Transmit/Receive Switch)	1	$8	$8
TI LM96550 (High Voltage Pulser Chip)	1	$20	$20
TI LM96570 (Digital Transmit Beamformer Chip)	1	$6	$6
PCBs	1	$20	$20
Diodes, R, L, C, etc.	~	$20	$20
		Parts Total:	$1516

GRAND TOTAL = LABOR + PARTS = $73,716

c. **Schedule:**

Week	Jonathan	Adam	Dean
1/30	● Research iPhone Programming ● Order BLE chips and breakout board	● Research Ultrasound Probe and A-Scan Procedure ● Put BNC connector on Probe	● Draft Proposal ● Research Tx/Rx Circuitry for Ultrasound
2/6 (Prop. Due)	● Characterize Probe ● Solder BLE chip to breakout board	● Download and inspect part datasheets for design feasibility ● Select battery to power device	● Order TI Tx/Rx Chips & breakout boards
2/13	● Construct BLE test circuit to light an LED on iPhone command and display an input voltage on screen	● Solder Beamformer and Pulser chips to breakout boards ● Implement voltage gain from Beamformer to Pulser	● Solder AFE & T/R Switch chips to breakout boards ● Implement Battery Power Supply
2/20 (DR Due)	● Draft Design Review ● Debug BLE test circuit and iPhone app	● Design Review Revision 1 ● Implement Beamforming and Pulse shaping, debug	● Design Review Revision 2 ● Implement TGC and ADC conversion, debug
2/27	● Modify BLE test circuit and app to handle array input and display the raw data	● Continue debugging Transmitter ● Connect Transmitter Circuit to Probe, debug	● Continue debugging Receiver ● Connect Receiver Circuit to Probe, debug
3/5	● Connect BLE to Analog Front End, debug	● Finish debugging Transmitter/Probe coupling	● Finish debugging Receiver/Probe coupling
3/12 (IPR Due)	● Individual Progress Report ● Finish debugging data from probe	● Individual Progress Report ● Collect sample data to prototype DSP/calculations	● Individual Progress Report ● Procure a sample eyeball
3/19 (Spr. Break)	● Design application user interface	● Design PCB	● Design Device Housing
3/26 (Mock-Up Demo)	● Implement application user interface	● Write Matlab code for DSP filtering and AEL calculations ● Request Initial PCB Fabrication from Parts Shop	● Prepare device and eyeball for mock-up demonstration ● Request help from Machine Shop for device housing
4/2	● Translate Matlab code into Objective-C and integrate it into application software	● Explain filtering and calculations in Matlab code for translation/integration	● Begin construction of device housing ● Request 1st Revision PCB Fabrication from Parts Shop
4/9	● Implement IOL calculator, graphics, etc.	● Request Final Revision PCB Fabrication from Parts Shop	● Finish construction of device housing
4/16	● Device testing and debugging	● Device testing and debugging	● Device testing and debugging
4/23 *(Demo and Presentation)*	● Final debugging ● Prepare slides on iPhone and BLE	● Final debugging ● Prepare slides on Probe and Transmitter Circuit	● Final debugging ● Prepare slides on Receiver Circuit and T/R Switch
4/30 *(Final Paper and Checkout)*	● Final Paper Revision 1	● Draft Final Paper	● Final Paper Revision 2