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# A Low Cost Open Source High Frame-Rate High-Frequency Imaging System

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***Abstract*— In this paper a low cost open source approach to high-frequency ultrasound imaging is described. This complete imaging system is based around four core components: A single-element geometrically focused imaging transducer, a low cost high frame-rate mechanical scanner, a field programmable gate array (FPGA) controlled pulser-receiver unit, and a data acquisition system running open source interface software. The single-element imaging transducer is spherically curved composite based on Lithium Niobate that has a centre frequency of 45 MHz, a bandwidth of 65%, and an insertion loss of -19dB. The mechanical scanning mechanism is based on a 45 mm long PZT bimorph attached to an extension arm. The mechanism can scan up to a 10 mm displacements at 100 Hz and is driven with a low cost Arduino microcontroller. The mechanism is mounted in an enclosed probe holder filled with deionized water. The FPGA accurately controlling the variable timing of the pulser-receiver unit is a Xilinx Virtex V and the data acquisition hardware consists of an off the shelf AlazarTech PCIe digitizing card and a PC. The hardware communication, GUI/plotting libraries, and data collection is all controlled with an open source Python application we have named OpenHiFUS.**

***Keywords—high frequency ultrasound, low cost; open source***

## I. INTRODUCTION

High-frequency ultrasound is still a relatively new technology that uses micro-fabricated ultrasound transducers operating in the 20-70MHz range to achieve imaging resolutions of a few tens of microns, an order of magnitude higher resolution than conventional ultrasound systems used in human diagnostic medical imaging. In recent years, there has been a big push to move high-frequency ultrasound systems to linear array-based technology instead of the previous generation of mechanically scanned single-element systems [1]. The most obvious advantage to using an array-based system is that the depth-of-field of the imaging transducer is increased over the single-element fixed-focus transducers. There are some other less dramatic advantages to the array system such as slightly higher frame rates and more versatile Doppler imaging. After noting the advantages of the array based system, it is also important to note the disadvantages. Perhaps the largest disadvantage of the array based system is the large channel count, which increases the system cost dramatically. Whether it be because the complexity of array micro-fabrication and interconnect issues, parallelized high speed data acquisition, or parallelized pulser-receiver hardware, it is obvious that the system cost is much higher for a linear array based system. Another significant disadvantage to the linear array-based system is the weakly focused elevation plane or poor slice resolution. In fact, if one were only interested in a region that falls within the depth of field of a single element imaging transducer, the image quality would be superior to that of a linear array-based system in that same region. Because of the large difference in price point, and the moderate difference in image quality, it is our belief that there is still a place for a low cost mechanically scanned high frequency ultrasound systems.

A high-frequency mechanically scanned ultrasound system typically consists of an imaging transducer, a scanning system, pulser-receiver unit, data acquisition hardware, and image processing/display software to turn the acquired signal into a set of images. We have developed a low cost open source imaging system with these components by using open source software, a low cost scanning actuator, and, for the most part, low cost electronic hardware. The system, as conceptually illustrated in Figure 1, is a progression from early work conducted to develop the mechanical scanning mechanism [2].

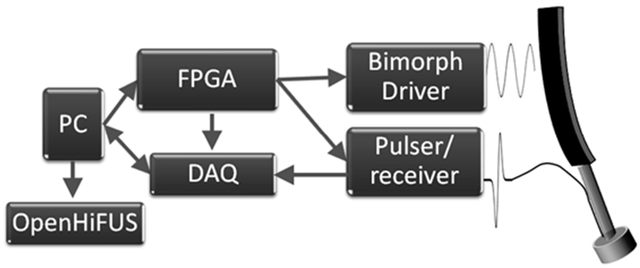


Figure 1: Block diagram of complete imaging system.

## II. SYSTEM DESIGN

Figure 2 shows a photograph of the complete imaging system with all components mounted within a commercially available medical cart (Ergotron, Saint Paul, MN). The system electronics are contained within the main drawer, a small form factor PC is mounted on the back of the cart, and the imaging probe with its integrated mechanical scanning mechanism is shown on top of the main drawer (A).


Figure 2: Photograph of complete imaging system.

## A. *Imaging Probe and Mechanica Scanner*

The imaging transducers used are commercially available 45 MHz single-element geometrically focused Lithium Niobate composite transducers (Daxsonics Inc. Halifax, NS). Two different transducers were used for data collected during this study with slightly different apertures and f/numbers. Both transducers have bandwidths of 65% and a single cycle excitation pulse insertion loss of -19dB (once compensated for water attenuation and the quartz reflector loss [3]). The first transducer was 3.0 mm in diameter and geometrically focused at f/3.0, the second was 2.5 mm in diameter and geometrically focused at f/2.8. Beam diffraction predictions for lateral beam widths are approximately 120 µm and 110 µm at the focus, and the anticipated depth-of-field values are 2.4 mm and 2.1 mm.

As shown in Figure 3, the imaging probes are mounted onto stainless steel extension arms and then epoxied to the free end of a 40 mm x 10 mm x 0.6 mm cantilevered piezoelectric bimorph. This bimorph serves as the mechanical scanning mechanism for the imaging probe [2]. When cantilevered at the base of the bimorph, and with the imaging probe submerged in water for acoustic transmission, the scanner operates at its resonance frequency of 95 Hz, potentially allowing up to 190 unique frames per second.

The probe and bimorph assembly is mounted inside a 3D printed plastic probe housing and filled with de-ionized water. For the acoustic window at the front of the casing, a 100 micron film of poly-methyl-pentene (TPX) was used. A fully assembled imaging probe and mechanical scanner is shown as held during use in Figure **4**.

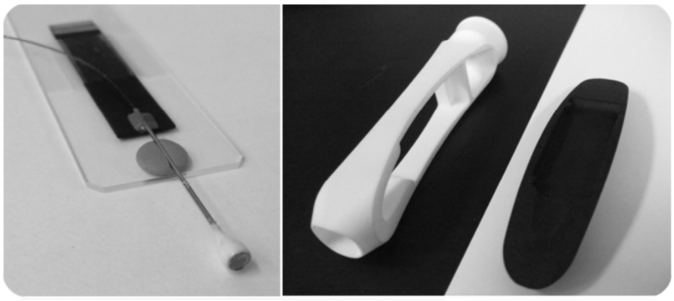

Figure 3: Imaging probe mounted onto stainless steel extension arm and piezoelectric bimorph (left); External casing for imaging probe and mechanical scanner (right).

Figure 4: Assembled imaging probe and mechanical scanner.

## B. *System Electroinics*

As shown in Figure 5, all system electronics (aside from the PC) are contained within a small drawer on the medical cart.

The bimorph driving electronics are based on an open source micro-controller (Arduino Nano), which is programmed to act as a sine wave generator using a direct digital synthesis (DDS) method. The signal synthesis is synchronized to the acquisition sequence using hardware triggers from the FPGA. The microcontroller also receives instructions to start/stop and to adjust signal amplitude and phase from the system PC. Output from the bimorph driver is passed through a low cost high voltage amplifier circuit and the signal can be adjusted up to ± 120 V, from which lateral displacements of over 10 mm can easily be achieved.

The pulser-receiver used is a custom design, very similar to the one described in [4]. The pulser is triggered by a low cost FPGA (Xilinx, Virtex V, San Jose, CA) using accurately controlled transmit pulses that correspond to 100 equally spaced image lines as the bimorph transitions from high velocity near the centre of the image to zero velocity at the frame edges. Additionally, this FPGA is used to generate a reference clock and corresponding timing triggers for the data acquisition system, along with the previously mentioned synchronization triggers for the bimorph driver. Generally speaking, the FPGA's primary function would be to accurately

synchronize the pulser, the scan-head, and the data acquisition clock.

The data acquisition, processing, and display system consisted of a PC containing a commercially available 500 MHz 12 bit PCIe digitizer (Alazar Technologies Inc., Pointe-Claire, QC) with acquisition synchronized to the triggers generated by the Arduino. The commercially available Alazar data acquisition card is by far the most expensive component in the system.

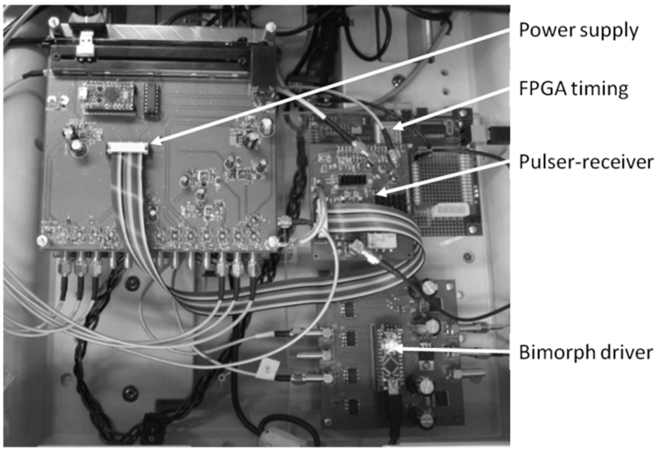


Figure 5: Photograph of system electronics contained in medical cart drawer.

### C. *Software Description*

The open source software developed for the system performs real-time data acquisition and processing using the Python language. A version of this software is currently available under the title OpenHiFUS [5] (Open High Frequency Ultrasound). The Python language was chosen to allow for simple customization by end users in various applications, and for the wealth of open source libraries available.

OpenHiFUS is predominantly based on a PyQt [6] framework, where a series of software widgets and objects are connected by internal Qt signals. This structure is illustrated in Figure 6, where the main application hosts three primary components: a micro-controller interface, a group of display windows imaging modalities, and a data processing object responsible for interacting with a secondary data collection process.

The micro controller widget interacts with the bimorph scanner via USB communication to start, stop, and adjust oscillation amplitude. Display windows are available for B and M mode ultrasound imaging as well as to display the unprocessed high frequency signal. Once processed, data is displayed in these widgets using the efficient Python library, guiqwt [7].

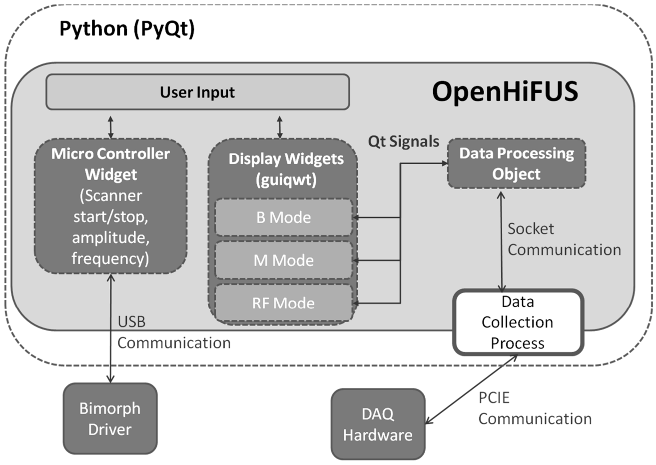


Figure 6: Illustration of OpenHiFUS software design.

The third and most critical component to OpenHiFUS is the data processing object. This is responsible for transmitting newly processed data to the display windows, for receiving processing instruction from the display windows (settings for averaging, noise threshold, time gain amplification, etc.), and for interfacing with the independently running data collection process. Data collection and interaction with the external DAQ hardware is handled by a second independently running process and communication between the main application and this second process is handled using software sockets. By using this approach the overall acquisition rate is maximized and unaffected by user interaction with the main application.

## III. RESULTS

### A. *System Performance*

Currently, the described low-cost hardware system running with OpenHiFUS on a standard contemporary PC has achieved 80 frames per second (fps) of simultaneous acquisition, processing and display. On the system discussed in the remainder of the paper a display rate of 47.5 fps was chosen, corresponding to every second oscillation of the 95 Hz mechanical scanner. Currently, the limitation preventing higher display frame rates is the serial calculations used to produce B mode images from the captured high frequency data. Additional work is underway to move these calculations to a parallel graphical processing unit to increase overall performance. It should be noted however that the system can save and replay images at the full potential frame rate of 190 fps.

### B. *Imaging Results*

Early stage evaluation of the system's imaging performance is presented here for a wire phantom, a human wrist image, and for a mouse cardiac sequence.

Figure 7 shows a wire phantom image obtained using 15 μm aluminum wire nominally spaced at 1 mm in a de-ionized water bath. The probe used for this image was 3.0 mm in diameter with a relatively low focus of f/3.0; these results

show, as expected, the image focal region and the achieved resolution. The best resolution is at the focal depth of 9 mm, but since the f/number is relatively low, there is a fairly large depth of field.

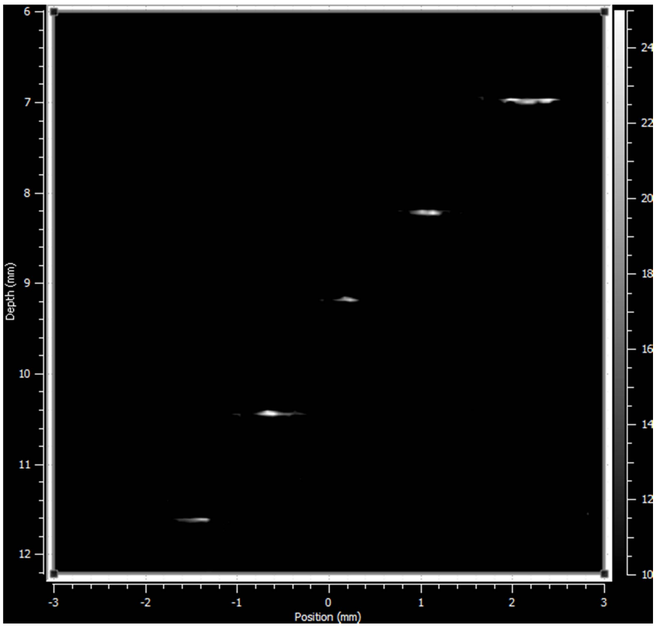


Figure 7: Water bath wire phantom image with 15 µm aluminum wire.

Figure 8 shows a B mode image of a vessel in a human wrist, taken using the same imaging probe as in the wire phantom image. Clearly visible is the structure of the dermus tissue, the boundaries of the artery, and speckel produced by blood flow within the artery.

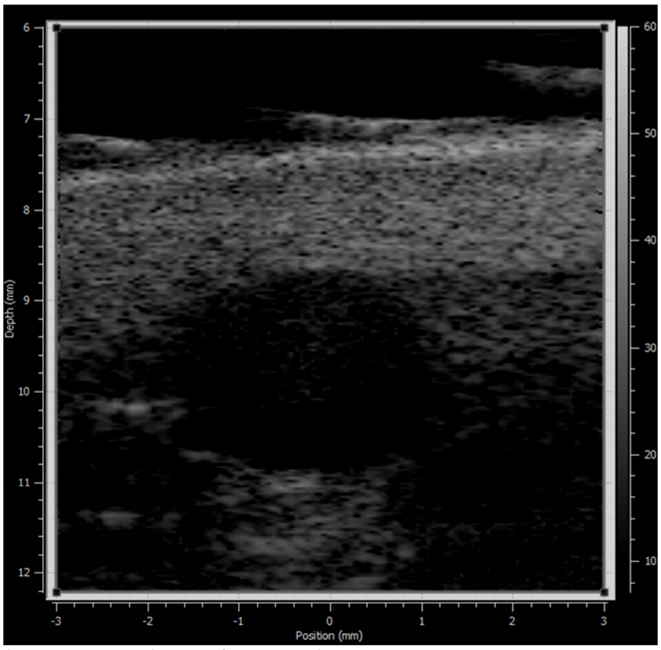


Figure 8: B mode image of human wrist artery.

Figure 9 shows an M mode sequence from a short-axis view of a mouse heart ventricle. Used for this sequence was the 2.5 mm, f/2.8 imaging probe. In this image the periodicity in the M sequence cleary shows a a heart rate of 370 bpm, as well as mimimum and maximum ventricle diameters. The open nature of the processing module should make it straightforward to add strain imaging and volumetric estimation, for instance, to the system.

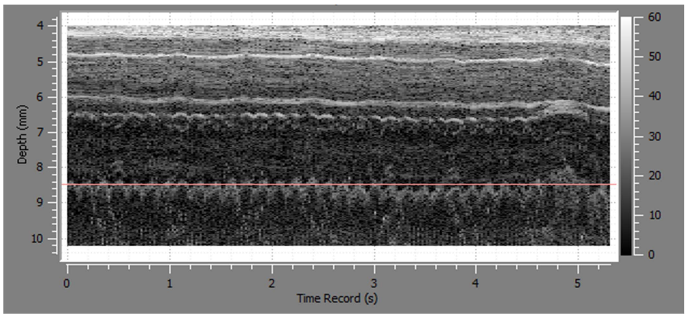


Figure 9: M mode sequence from short-axis cross section of mouse ventricle.


## ACKNOWLEDGMENT

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