Software Framework of a Real-time Pre-beamformed RF Data Acquisition of an Ultrasound Research Scanner

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ABSTRACT

Acquisition of pre-beamformed data is essential in advanced imaging research studies such as adaptive beamforming, synthetic aperture imaging, and photoacoustic imaging. Ultrasonix Co. has developed such a data acquisition device for pre-beamformed data known as the SONIX-DAQ, but data can only be downloaded and processed offline rather than streamed in real-time. In this work, we developed a software framework to extend the functionality of the SONIX-DAQ for streaming and processing data in near real-time. As an example, we applied this functionality to our previous work of visualizing photoacoustic images of prostate brachytherapy seeds. In this paper, we present our software framework, applying it to a real-time photoacoustic imaging system, including real-time data collection and data-processing software modules for brachytherapy treatment.

1. INTRODUCTION

Acquisition of pre-beamformed data is essential in advanced imaging research studies such as adaptive beamforming, synthetic aperture imaging, and photoacoustic imaging. Specifically, photoacoustic imaging for brachytherapy seed localization is also being investigated by several research groups [1-5].

Photoacoustic imaging (PAI) is a hybrid medical imaging modality that exploits the properties of light and ultrasound by scanning the distribution of optical absorption in material. PAI is based on the photoacoustic effect, which is the conversion of light waves to acoustic waves through optical absorption, localized thermal excitation, and localized pressure transient of tissue. Also, PAI has high contrast and resolution. Thanks to the merits of PAI, PAI has been used in biomedical imaging areas such as various structural and functional imaging applications.

In photoacoustic imaging technology, acoustic waves are generated simultaneously in the entire volume of irradiated tissue by laser beam. To analyze the distribution of optical absorption in tissue using acoustic waves generated from the photoacoustic effect, the acoustic waves should be recorded on every element of an ultrasound transducer array simultaneously. That is, pre-beamformed RF data is necessary to create a photoacoustic image. Access to pre-beamformed data has recently been made available for Ultrasonix ultrasound systems through the SONIX-DAQ device.

In our previous work [4], we performed a feasibility-test related to the visualization of multiple brachytherapy seeds using photoacoustic imaging, demonstrating that photoacoustic imaging is clearer than TRUS imaging for monitoring the locations of brachytherapy seeds in a brachytherapy operation. Moreover, we collected photoacoustic images of seeds in ex-vivo tissue using the SONIX-DAQ device [5]. However, in these works, the procedure of reconstructing a photoacoustic image was not carried out in real-time, but off-line. The SONIX-DAQ device (Ultrasonix Co.) and a control software of the device (DAQ control software, Ultrasonix Co.) acquired pre-beamformed Radio-Frequency (RF) data, which contained information of the acoustic waves emitted from the brachytherapy seeds by the photoacoustic effect, and saved the data on the local hard-disk drive [6]. After the experiment, the saved data is loaded to reconstruct a photoacoustic image in MATLAB software (Mathworks, Inc.) and with a MATLAB script file. This procedure is not efficient for intra-operative treatment of inserting brachytherapy seeds into prostate tissue.

Figure 1 shows an overview of our new system for generating photoacoustic images in real-time. As seen in the figure, our system can be divided into two groups: ultrasound imaging and laser system. These two groups are synchronized by

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a Transistor-Transistor Logic (TTL) control signal of the laser system. The overall system configuration is similar to our previous work [5], except the ultrasound imaging part. Software framework of the ultrasound imaging part is now based on the *MUSiiCToolkit* [7] and *OpenIGTLinkMUSiiC* [8]. In this research, we improved the software framework for building real-time photoacoustic images by adding real-time data collection (*DAQ-Server*) and data-processing (*BeamForm*) modules (see Figure 1). Although here we apply the software specifically to photoacoustic imaging of brachytherapy seeds, it can also be used more generally in any application requiring the SONIX-DAQ. This paper is organized as follows: Section 2 describes our software architecture with detailed explanation of each software module. In Section 3, we present results of our development with a discussion.

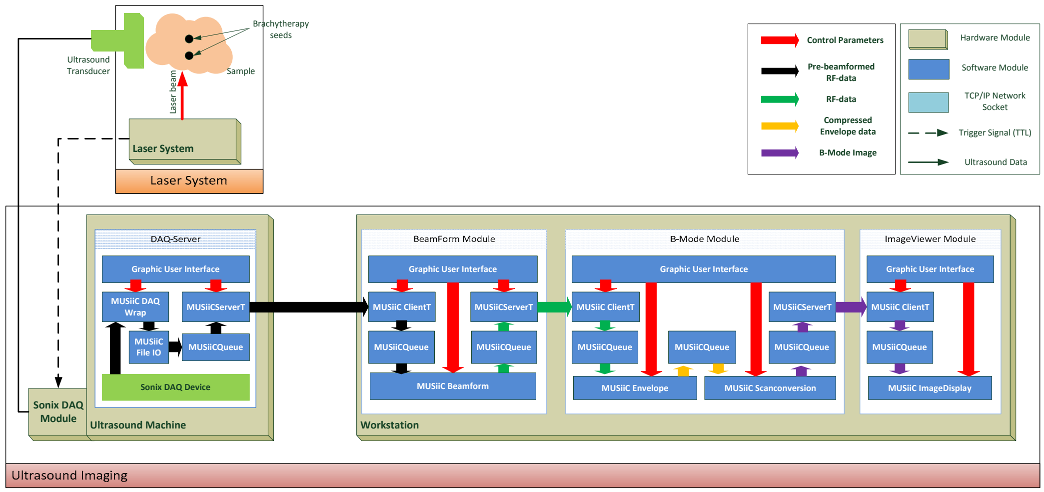

Figure 1 Block diagram of real-time photoacoustic imaging system

2. METHODS

As seen in Figure 1, the software framework of the photoacoustic imaging system is composed of two existing modules of the *MUSiiCToolkit*: the *B-Mode* module and the *Image-Viewer*. The *DAQ-Server* and *BeamForm* modules are newly developed for real-time data acquisition and data processing. The *MUSiiCToolkit* [7] is composed of several specialized executable programs based on network-distribution systems and multithreaded architecture. Ultrasound data such as pre-beamformed RF data, post-beamformed RF data, or Image data is communicated between software modules using an extension version of *OpenIGTLink*, named *OpenIGTLinkMUSiiC* [8].

2.1 *DAQ-Server* module

To collect pre-beamformed RF data, we used the SONIX-DAQ device (Ultrasonix Co.) [6] that was designed for the collection of multi-channel pre-beamformed RF data from ultrasound transducers and a conventional ultrasound machine, such as the SONIX-CEP (Ultrasonix Co.) [6]. Although there are control software and Software Development Kit (SDK) for this device provided from the company, both of them cannot support a functionality of providing a pre-beamformed RF data stream in real-time. Thus, we built the *DAQ-Server* to achieve our needs by customizing the SDK of the SONIX-DAQ device and integrating it with several functional classes of the *MUSiiCToolkit* [7] and *OpenIGTLinkMUSiiC* [8].

Figure 2 represents a flowchart of the *DAQ-Server*. As seen in the figure, the *DAQ-Server* is composed of three classes of the *MUSiiCToolkit* and *OpenIGTLinkMUSiiC*: *MUSiiCFileIO*, *MUSiiCQueue*, and *MUSiiCServerT* classes. *MUSiiCDAQWrap* class is a customized class of the provided SDK. Using this class, pre-beamformed RF data is collected from the SONIX-DAQ device and saved on the local hard drive. Then, *MUSiiCFileIO* class reads the saved pre-beamformed RF data, puts the data into *MUSiiCQueue*, which is a thread-safety queue for multithreaded architecture. Finally, the pre-beamformed RF data will be sent to multiple clients by the *MUSiiCServerT* class that supports multiple-client connections as a network class of *OpenIGTLinkMUSiiC* [8].

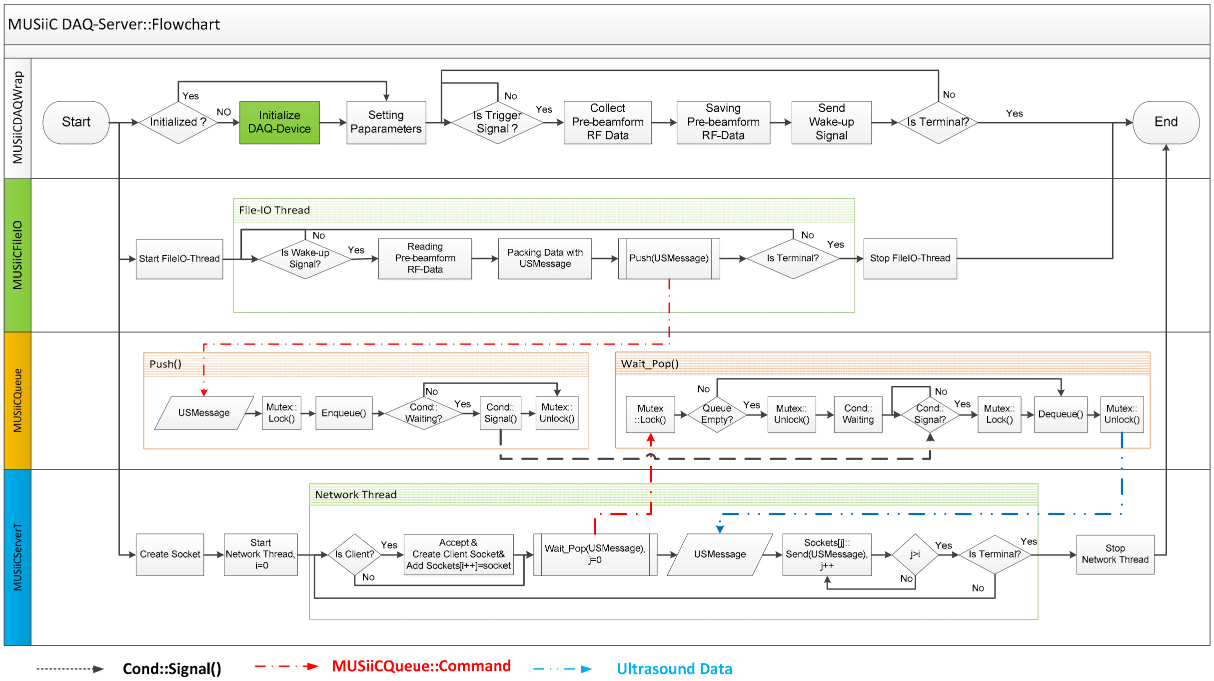

Figure 2 Flowchart of *DAQ-Server*

2.2 *BeamForm* Module

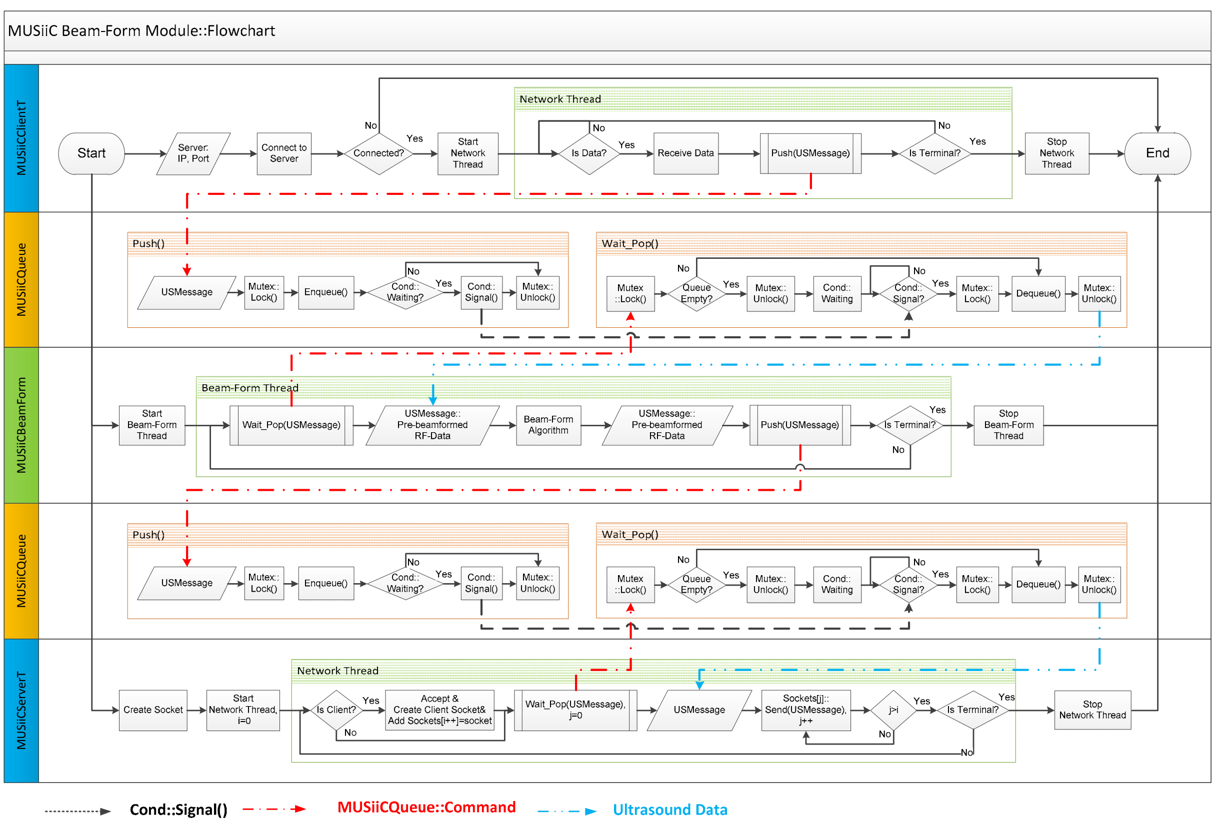

Figure 3 Flowchart of *BeamForm* module

The first step of building photoacoustic images from collected pre-beamformed RF data is converting the collected data into beamformed RF data. In our software architecture, the *BeamForm* module carries out this conversion. Figure 3 shows a flowchart of the *BeamForm* module. There are four functional classes in the *BeamForm* module: *MUSiiCClientT*, *MUSiiCQueue*, *MUSiiCBeamform*, and *MUSiiCServerT*. The *MUSiiCClientT, MUSiiC-Beamform*, and *MUSiiCServerT* classes are active classes that have their own independent task-thread. To communicate data between these active classes, two instances of *MUSiiCQueue* are in the *BeamForm* module.

The *MUSiiCClientT* class receives the pre-beamformed RF data stream from the *DAQ-Server* via TCP/IP network. Then, the received data is converted to beamformed RF data in the *MUSiiCBeamForm* class. The output data will then be transferred to the *B-Mode* Module [7] of the *MUSiiCToolkit* to create photoacoustic images in the *MUSiiCServerT* class.

2.3 *B-Mode* Module

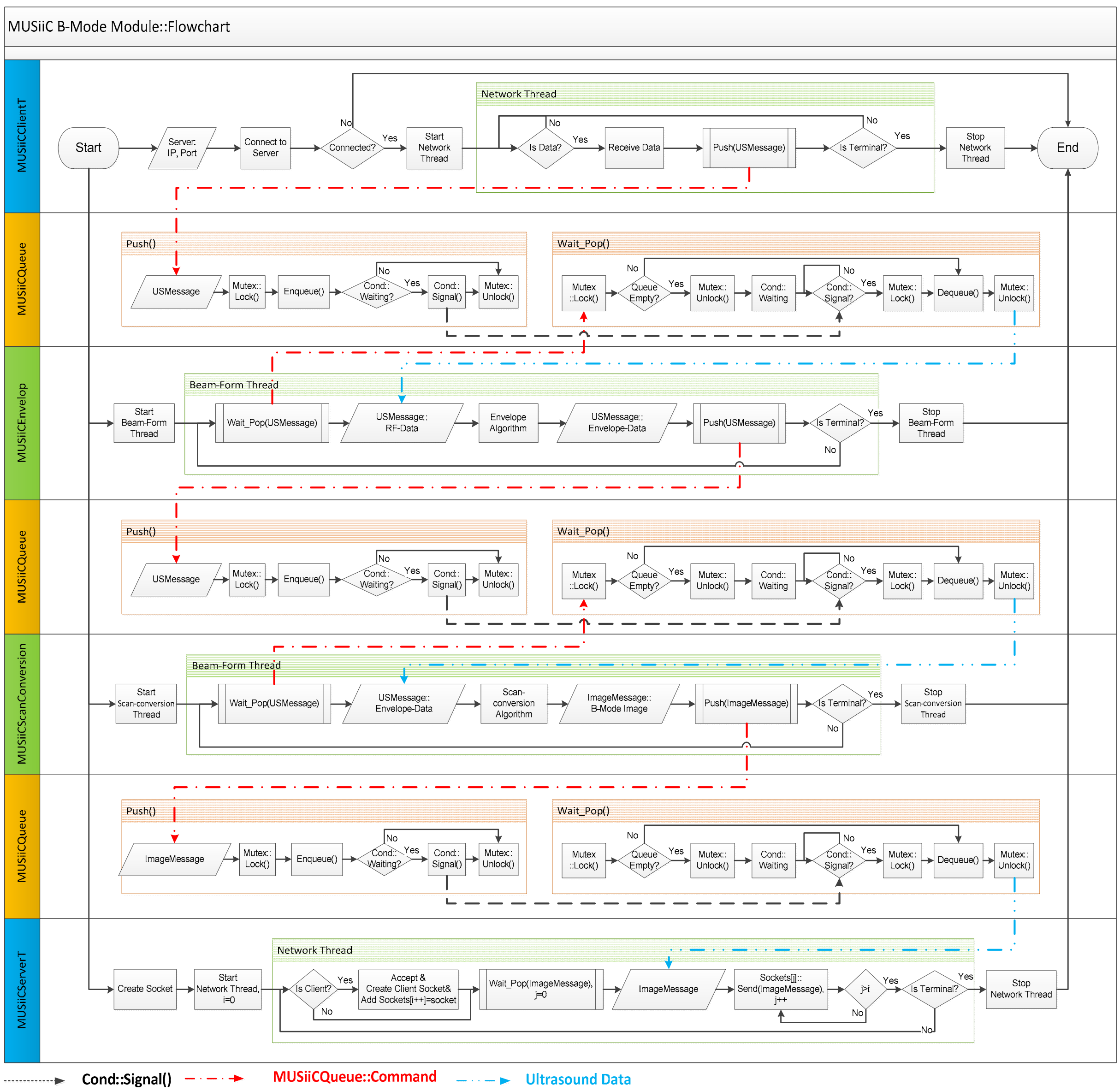

Figure 4 Flowchart of *B-Mode* module

The flowchart of *B-Mode* module appears in figure 4. As the figure indicates, RF data is received by *MUSiiCClientT* via TCP/IP network. Similarly with the *BeamForm* module, this module also has *MUSiiCClientT*, *MUSiiCQueue*, and *MUSiiCServerT* classes. Although the *BeamForm* and *B-Mode* modules are on the same workstation, TCP/IP network communication is used between these two modules for Inter-Process Communication (IPC). Afterwards, two active classes, *MUSiiCEnvelope* and *MUSiiCScanConversion*, get data from *MUSiiCQueue* and generate a B-Mode image. The output B-Mode image will be packed with an *ImageMessage* of *OpenIGTLink*[9] for communicating with existing image-guided systems such as *3D-Slicer*, and then sent to another client program to be displayed.

2.4 *Image-Viewer* Module

As stated in the previous section, photoacoustic image streams are packed with *ImageMessage* of *OpenIGTLink*[9]. While *3D-Slicer* can display an *ImageMessage*, this program cannot keep a network connection continuously. So, we built the *ImageViewer* module to display photoacoustic image streams with real-time. Using *MUSiiCClientT* and *MUSiiCQueue* class, this module can receive consecutive photoacoustic images. Moreover, a rendering function of *ImageMessage* and basic image processing functions, zooming in/out, adjusting contrast and brightness of image, are implemented on the *MUSiiCImageDisplay* class.

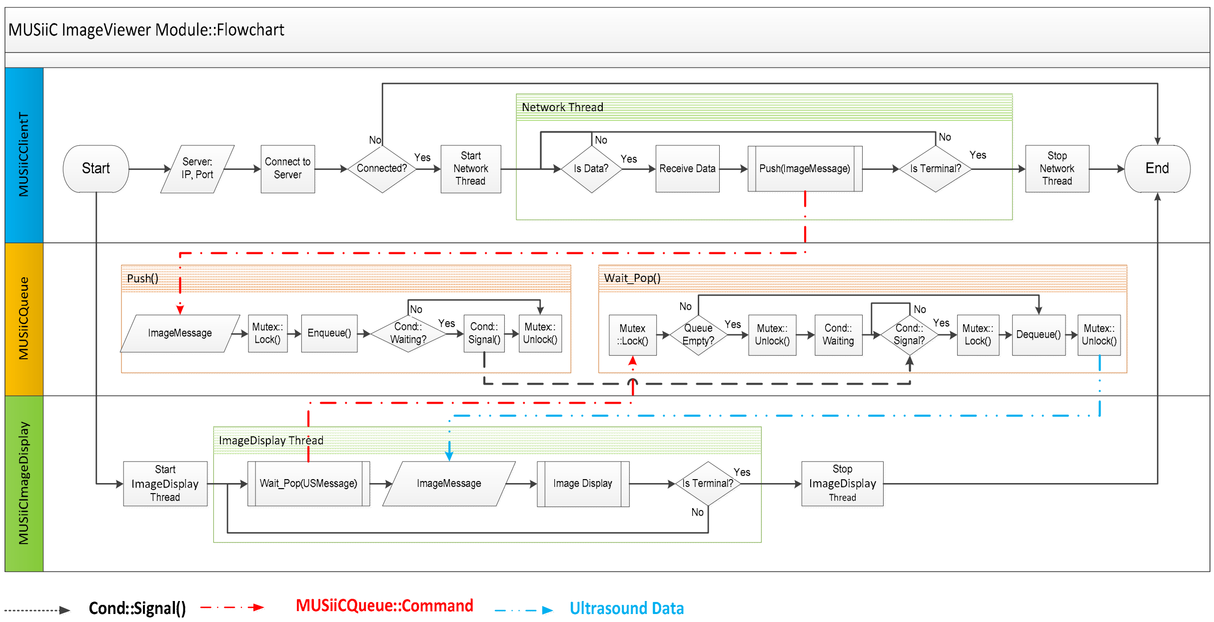

Figure 5 Flowchart of *ImageViewer* module

2.5 Phantom experiment

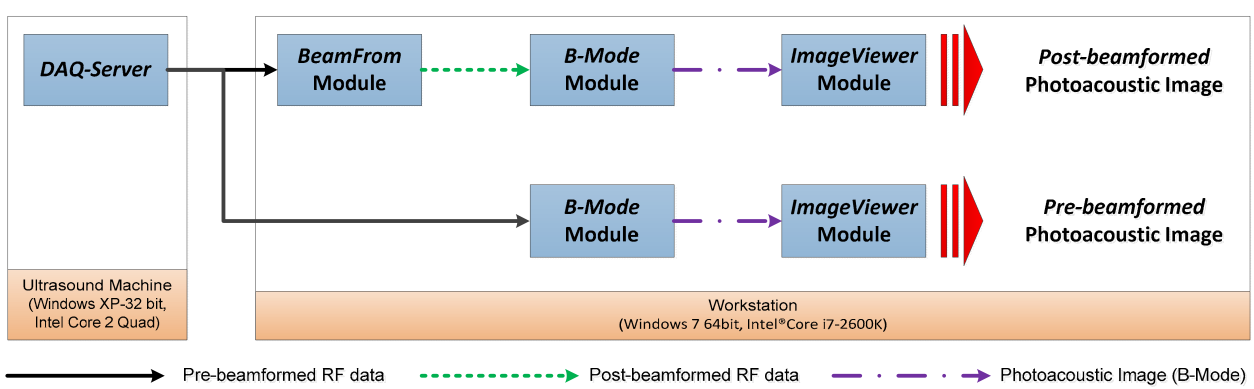

Figure 6 Block diagram of phantom experiment.

Figure 6 shows the block diagram of our phantom experiment. The goal of our experiment is to generate post-beamformed photoacoustic images and pre-beamformed photoacoustic images simultaneously. Pre-beamformed RF data that is collected on the DAQ-Server is transferred in two data-processing pipelines: the post- and the pre-beamformed photoacoustic image pipelines. The *Beamform* module of the post-beamformed photoacoustic pipeline converts pre-beamformed RF data to post-beamformed RF data with an aperture size 32 using standard delay-and-sum reconstruction. The *B-Mode* module of both pipelines generates ultrasound B-Mode images from RF data.

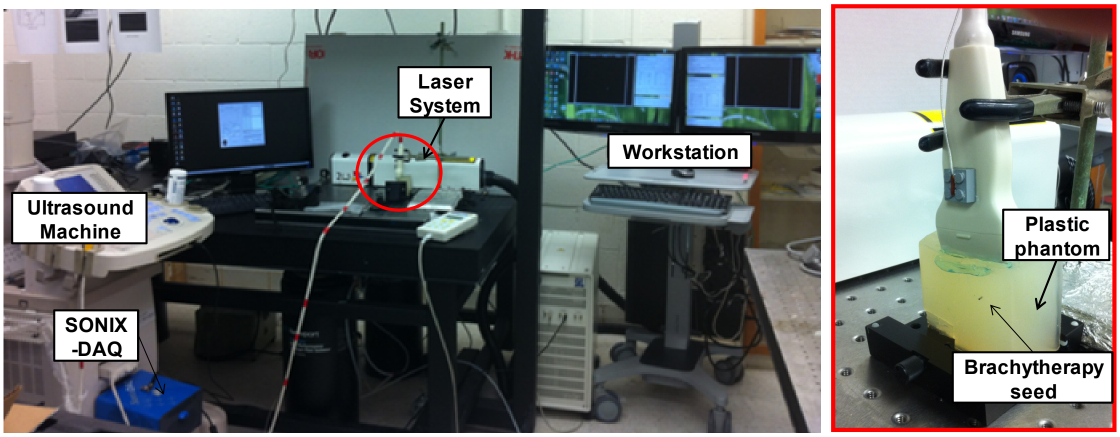

Figure 7 System setup of phantom experiment.

Figure 7 shows the system setup for a real-time pre- / post-beamformed photoacoustic imaging experiment. For collecting pre-beamformed RF data, we used the ultrasound machine, SONIX-CEP (Ultrasonix Co.), and the data acquisition device, SONIX-DAQ (Ultrasonix Co.), as was mentioned above. Also, the laser system, Brilliant (QUANTEL.), was used to generate the photoacoustic effect in the plastic phantom. The data-acquisition device (SONIX-DAQ) and the laser system are synchronized by TTL control signal from the controller box of the laser system. The brachytherapy seed that is implanted into the plastic phantom is a decayed Palladium-103 seed (Theragenics Co.) encapsulated in a titanium cylindrical shell 0.8 mm in diameter and 4.5 mm in long.

3. RESULTS

In this research, we developed a software framework which is composed of specialized executable programs for a real-time photoacoustic imaging system. The software framework enables the collection of pre-beamformed RF data and generates photoacoustic images from the collected data in real-time. Moreover, multiple program sets related with data-processing and display (*BeamForm*, *B-Mode* and *ImageViewer* modules) can be connected on one raw-data provider (*DAQ-Server* module) due to the functionality of the *MUSiiCServerT*, which supports multiple-client connections. By implementing several different beamforming algorithms on the *BeamForm* module of each program set, different photoacoustic images are easily generated and compared with each other in real-time.

In our phantom experiment, the *DAQ-Server* module has been tested on the SONIX-CEP (Windows XP-32 bit, Intel Core 2 Quad), and the *BeamForm*, *B-Mode*, and *Image-Viewer* modules were executed on a Pentium 4 PC workstation (Windows XP 64bit Intel i7). The *DAQ-Server* collected and sent out pre-beamformed RF data with around 3 frames per second (fps), and then the *BeamForm* and *B-Mode* modules generated photoacoustic images from the acquired pre-beamformed RF data. Therefore, the overall performance (fps) of our system is around 3 fps. This performance depends on the depth of a photoacoustic image.

Figure 8 show the pre- / post-beamformed photoacoustic images that are generated simultaneously from our real-time photoacoustic imaging system. In the photoacoustic images, there is a white spot and line. The lower white spot represents the brachytherapy seed in the plastic phantom. The upper white line is an echo off the phantom wall. The location of the lower white spot corresponds with our position of the brachytherapy seed in the plastic phantom.

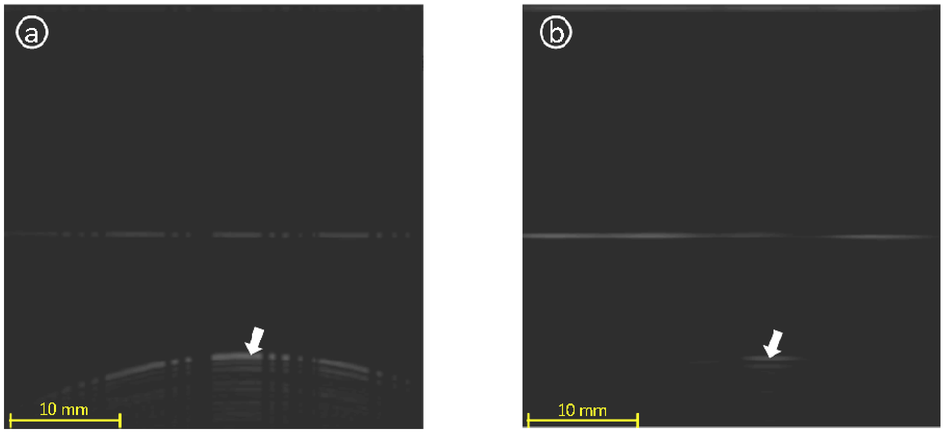

Figure 8 Photoacoustic images (width: 38 mm, height 38.5: mm) of a single brachytherapy seed (white arrow): (a) pre-beamformed photoacoustic image, (b) post-beamformed photoacoustic image

4. CONCLUSION

In this research, we built a real-time photoacoustic imaging system using our *MUSiiCToolkit* [7], which is a modular real-time toolkit for advanced ultrasound research, and *OpenIGTLinkMUSiiC* [8], that is an extended version of *OpenIGTLink* [9] for communication protocol for advanced ultrasound research. In our setup, the ultrasound imaging system and the laser system are synchronized via a TTL signal of the laser machine. Pre-beamformed RF data is acquired from the SONIX- DAQ device and the *DAQ-Server* module, and then the data is converted to a photoacoustic image in our *BeamForm* and *B-Mode* modules.

Moreover, our software is based on network-distributed software and a modular program scheme. That is, all the modules of our *MUSiiCToolkit* including *DAQ-Server*, *BeamForm*, *B-Mode*, and *Image-Viewer* modules have network classes of *OpenIGTLinkMUSiiC* (*MUSiiCServerT*, *MUSiiCClientT,* or both) that support multiple-client connection via TCP/IP network simultaneously. Therefore, we can test various algorithms on the same source data. In the case of photoacoustic imaging, several different beamforming algorithms can be carried out on the same pre-beamformed RF data simultaneously. The results can thus be compared in real-time.

From our experiment, we see that our new software framework can be applied not only to photoacoustic imaging of brachytherapy seeds, but to any application that requires the streaming of pre-beamformed RF data from the SONIX-DAQ device or pre-beamformed RF data processing.

5. REFERENCES

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