

A Virtual Ultrasound Imaging System for Studying Transducer and Pulse Parameters Effects on Image Quality

Wael Abdel Rahman¹, Ahmed Morsy²

¹Department of Electrical Engineering, Benha High Institute of Technology, Benha, Egypt

²Department of Biomedical Engineering, Cairo University, Cairo, Egypt

Abstract—This paper presents an initial implementation of a Virtual Ultrasound Imaging System as an interactive educational tool for students and researchers in the medical ultrasound imaging field. The system uses a cause and effect approach for understanding the results of changing transducer attributes and pulse parameters on the quality of the ultrasound image. The elements of the system include Field II simulation program, MATLAB computational environment, and computer generated test phantoms. The system allows the user to change the array type (linear, convex, and phased), the array parameters (e.g., the number of elements and the element dimensions), the pulse parameters (center frequency and bandwidth), and the phantom type. An easy to use graphical user interface has also been developed to facilitate the use of the virtual ultrasound system. The system should prove valuable for teaching and research purposes.

Keywords— FIELD II, Medical Ultrasound, Ultrasound Phantoms, Ultrasound Transducers, Virtual Ultrasound Imaging System.

I. INTRODUCTION

Ultrasound imaging is one of the most utilized imaging modalities used for non-invasive medical diagnosis. The main reasons for the dominance of ultrasound imaging are the demonstrated safety and the real time aspect associated with its use. Ultrasound is also capable of imaging soft tissue and blood flow, and is considered a low cost imaging modality. In addition, there are no special building or setup requirements as for X-ray, Nuclear imaging, and Magnetic Resonance imaging [1]. In ultrasound imaging, it is important to study the effect of changing the parameters of various system elements on the quality of the produced image.

Virtual Ultrasound Imaging Systems present effective tools for studying and analyzing the effect of changing system parameters on the outcome. The concept of Virtual Ultrasound Imaging Systems was presented by Duke University researchers and was made available on the university website [2]. They used an approach based on prestoring a large number of images corresponding to various system settings using a Siemens Elegra ultrasound scanner. A web-based user interface is used to change system parameters (e.g., image depth, focus depth, and gain), which causes the system to recall and display one of the prestored images. The main purpose of that system was educational. A major drawback is that the system did not

address the effect of varying the transducer or pulse parameters.

This paper presents a different approach for constructing a Virtual Ultrasound Imaging System. The approach is based on simulations performed using the FIELD II program, MATLAB computational environment, and computer generated ultrasound test phantoms. Simulated images are saved in a database to be retrieved later using the user interface of the Virtual Ultrasound Imaging System.

The elements and capabilities of the Virtual Ultrasound Imaging System are presented in section II. Computer generated phantoms used by the system are discussed in section III. Examples of the results are given in section IV, and the conclusions of this work are presented in section V.

II. THE VIRTUAL ULTRASOUND IMAGING SYSTEM

The main goal of building a virtual ultrasound imaging system is to streamline the process of studying the effect of changing the parameters of an ultrasound imaging system on the produced image. Fig. 1. shows a block diagram for the Virtual Ultrasound Imaging System. The system consists of three main parts. The first part is concerned with selecting the input parameters to the system where the user can select the transducer type, transducer parameters, pulse parameters, and the phantom to be imaged. The second part is the processing part, which consists of three sections: FIELD II Program, MATLAB computational environment, and a MATLAB graphical user interface (GUI). The third part is the display of the resulting image.

In this system, the user has a variety of parameters that can be changed. The user can select the array type (linear, phased, or convex array transducer), the array parameters (the number of elements of the array, the number of active elements, and the element width and height, as well as the kerf of the array). The user can also select the pulse parameters (center frequency and bandwidth). The last step is to select the phantom type, where the user can choose from a number of predefined phantoms. When the user presses the "Update Image" button in the MATLAB GUI, the program chooses a previously created and stored image and sends it to the display module.

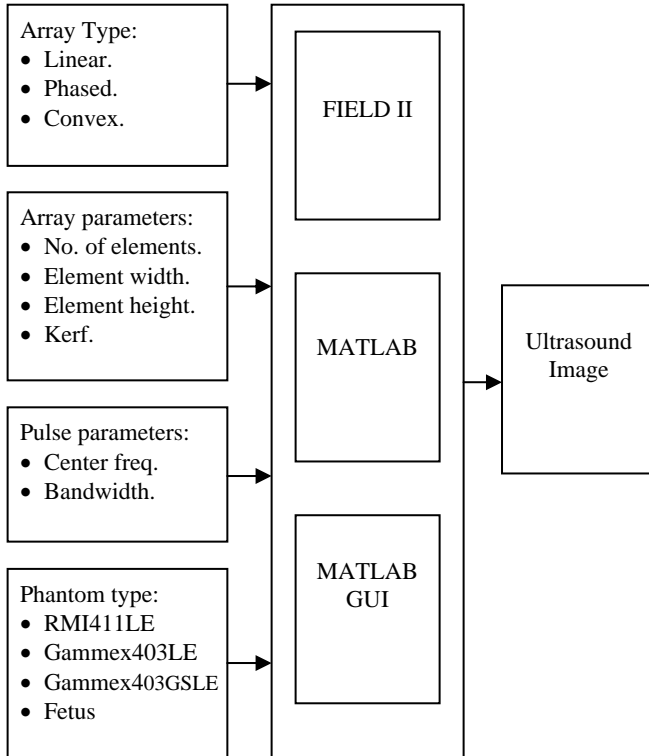


Fig. 1. Block diagram of the virtual ultrasound imaging system.

Internally, the virtual ultrasound imaging system uses the FIELD II and MATLAB programs. The FIELD program is a program for the simulation of ultrasound systems [3]. It is based on the Tupholme-Stepanishen method [4], [5] of spatial impulse responses, which assumes linear propagation. A newer version of the program, FIELD II, was developed with a very close interface to MATLAB. This makes it possible to make scripts for performing ultrasound imaging simulations [6].

Using FIELD II makes it possible to handle any transducer geometry. The program has the advantage of having pre-defined types of transducers, e.g., piston or concave single element, linear array, phased array, convex array, and 2D matrix array. The program can be found at the web site [7] where the executable code freely can be downloaded.

III. COMPUTER PHANTOMS

An important step in designing ultrasound imaging systems is selecting the appropriate set of design parameters. This step usually entails solving a number of engineering tradeoffs. Among these design parameters are the number of elements in the array transducer, the number of channels in the beamformer, and the focusing strategy in terms of the number of focal zones and apodization.

To test the effect of choosing various tradeoff strategies, it is usually constructive to use test phantoms. These phantoms typically mimic the actual tissue in terms of ultrasound propagation and attenuation properties. They also typically include a number of hyper-echoic regions (mimicking solid lesions) and hypo-echoic regions (mimicking cysts) with various contrast levels. These phantoms also typically include a number of point targets with various distances of proximity and relative orientation.

Different physical and computer phantoms can be found in the literature. Each phantom is concerned with studying one or more of the imaging system parameters. One example is a phantom that consists of a number of point targets [8]. This phantom is suited for showing the spatial variation of the point spread function for a particular transducer, evaluating focusing and apodization schemes, and can give an indication of side lobe levels. Another phantom contains a number of cysts and a number of highly scattering regions [9]. This phantom can be used for characterizing the lesion-contrast detection capabilities of an ultrasound imaging system.

Another type of phantoms is the Anatomic phantom, which attempts to generate images that mimic certain body organs. Two examples of such phantoms are a fetus in the third month of development and a left kidney in a longitude scan. These phantoms give an indication of the whole system's capabilities in real imaging situations.

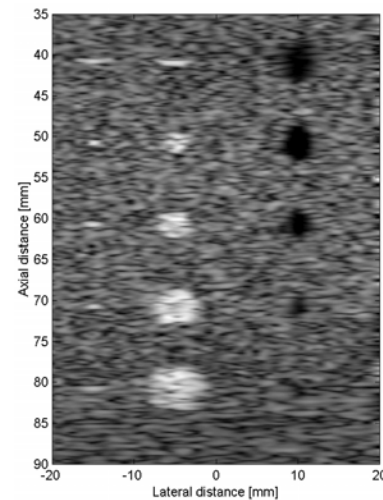


Fig. 2. Computer phantom with point targets, cyst regions, and solid lesions.

In our system, four computer phantoms were used. The used phantoms are: RMI411LE, Gammex403LE, Gammex403GSLE, and a fetus phantom. The first three phantoms are downloaded from the site of Gammex RMI company [9]. The last one is a computer generated 12 week fetus anatomic phantom.

IV. RESULTS

The graphical user interface of the system consists of two parts, the first is a window to select the transducer type, and the second (shown in Fig. 3.) is where the user selects the rest of the parameters. By pressing the button "Update Image", both the phantom and its image will be displayed. In this window, a help button is also available. When the help button is pressed, an explanation window will appear, where we tried to describe the whole system and explain the effect of changing each parameter on the presented image.

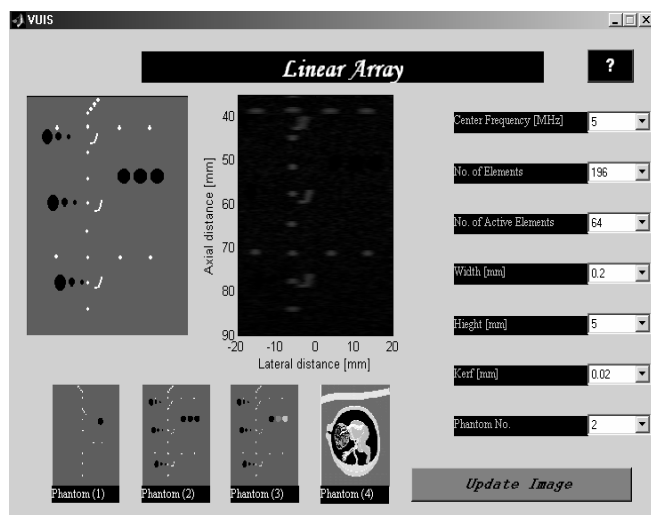


Fig. 3. The Virtual Ultrasound Imaging system GUI (Linear Array section)

Fig. 4 shows the Gammex403LE phantom. This phantom consists of multiple anechoic cyst regions and multiple highly scattering regions with different diameters. This phantom can be used to characterize the contrast-lesion capabilities of the imaging system.

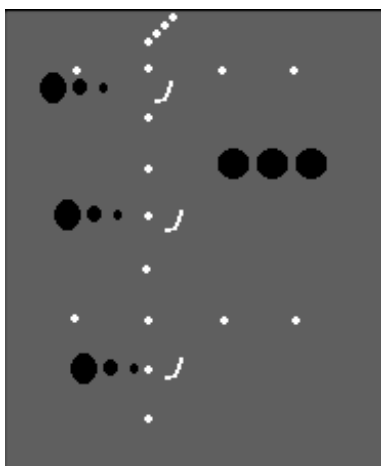


Fig. 4. The Gammex403LE phantom

We used a linear array transducer to scan the phantom. The linear array was 192 elements, with 64 active elements and a Hanning apodization in transmit and receive. The element height was 5mm, the width was one wavelength, and the kerf was 0.05mm. A single transmit focus was placed at a depth of 60mm, and receive focusing was done at 20mm intervals starting at 30mm from the transducer surface. The resulting image using 50,000 scatterers is shown in Fig. 5.a at 5MHz center frequency. Fig. 5.b shows the resulting image if we decrease the number of active elements to 16 active elements.

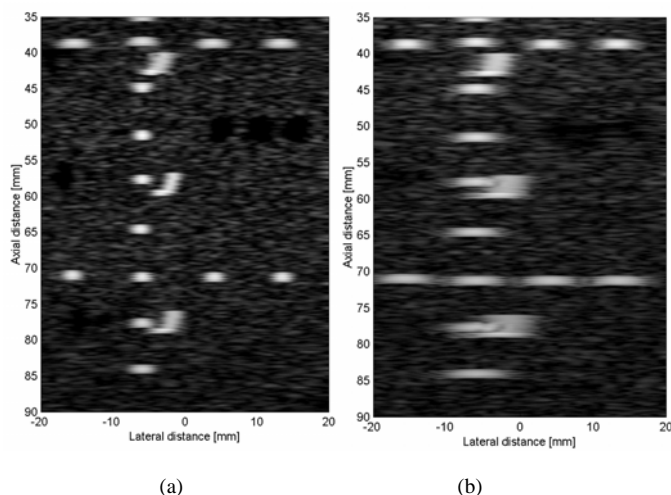


Fig. 5. The resulting Images (a) at 64 active elements (b) at 16 active elements

By comparing the phantom with the resulting images, we can see that the cysts look smaller and the one with very small diameters have almost disappeared, but the highly scattering regions are stretched. By comparing the two images in Fig. 5 we can notice that how the lateral resolution gets worse when the number of active elements (corresponding to the aperture size and the number of beamformer channels) decrease. This is in agreement with the theory. The Virtual Ultrasound Imaging System can also be used to obtain measures of the actual lateral resolution and compare them with theoretically predicted values.

Another example, shown in Fig. 6, demonstrates the effect of changing the ultrasound pulse itself. The images were obtained using the Gammex403LE phantom. Fig. 6.a shows an image using a pulse center frequency of 2.5MHz. The array type and parameters are similar to those used in Fig. 5. The comparison image, shown in Fig. 6.b, is obtained using a 5 MHz pulse. Again, it is very easy and constructive to observe the effect of changing the pulse center frequency on the resulting image. This example may be used in an educational setting demonstrates the tradeoff between improving the spatial resolution by increasing the pulse center frequency at the expense of reducing the penetration ability of the ultrasound system. It is also possible to obtain quantitative measures off the images themselves.

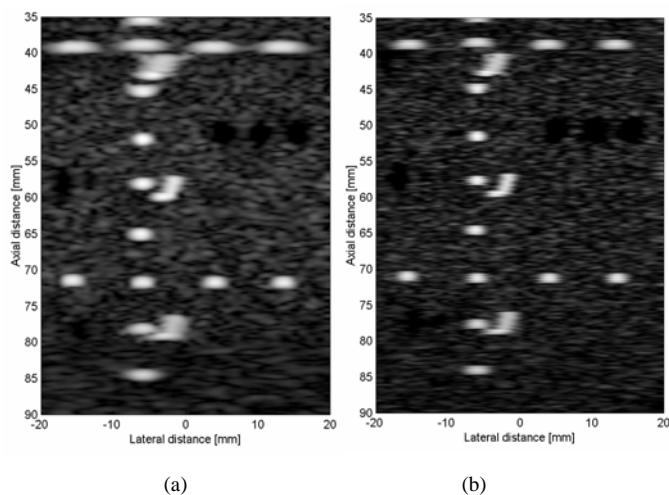


Fig. 6. The resulting Images (a) at 2.5MHz (b) at 5MHz center frequency

The phantoms used in this work typically consist of 50,000 scatterers. Simulating 50 RF lines takes about 6 hours using a Pentium 4 computer with a 2.4GHz processor and 256MB RAM to generate each of the phantom images using MATLAB 6 and the FIELD II program. Images are stored and properly indexed for later retrieval according to the selected system parameters.

V. CONCLUSION

This paper presented the preliminary results of implementing a Virtual Ultrasound Imaging System intended for use by students and researchers in the ultrasound imaging field. The system is based on performing simulation runs using the FIELD II simulation program, MATLAB computational environment, and computer generated ultrasound phantoms. Various parameters of the transducer arrays and imaging pulse can be changed using a simple graphical user interface and the effects of the changes can be displayed for analysis. The system is easy to use and should prove valuable in both academic and industrial settings. Future work may include enhancing the user interface to support direct measurements of spatial and contrast resolution. It may also prove useful to add a set of features for measuring speckle SNR, axial and lateral correlation, and various histogram-based calculations.

REFERENCES

- [1] Bjørn A. J. Angelsen, "Ultrasound Imaging Waves, Signals, and signal processing", Volume I, Dec 2000: Emantec, Norway.
- [2] <http://dukemil.egr.duke.edu/Ultrasound/VIS/ultra.html>.
- [3] J. A. Jensen. "Field: A program for simulating ultrasound systems." *Med. Biol. Eng. Comp.*, 10th Nordic-Baltic Conference on Biomedical Imaging, Vol. 4, Supplement 1, Part 1:351–353, 1996b.

- [4] G. E. Tupholme. "Generation of acoustic pulses by baffled plane pistons." *Mathematika*, 16:209–224, 1969.
- [5] P. R. Stepanishen. "Transient radiation from pistons in an infinite planar baffle." *J. Acoust. Soc. Am.*, 49:1629–1638, 1971.
- [6] J. A. Jensen, "speed accuracy trade-offs in computing spatial impulse response for simulating medical ultrasound imaging". *Journal of Computational Acoustics*, 9(3):731-744,2001.
- [7] <http://www.it.dtu.dk/~jaj/field/field.html>.
- [8] P. Munk and J. A. Jensen, "Computer phantoms for simulating ultrasound b-mode and cfm images". In S. Lees and L. A. Ferrari, editors, *Acoustical Imaging*, volume 23, pages 75–80, 1997.
- [9] <http://www.Gammex.com>.