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► **To cite this version:**

François Gaits, Gauthier Bouyjou, Enrico Boni, Alessandro Ramalli, Piero Tortoli, et al.. A Framework for Real-Time Visualization of Experimental and Simulated Ultrasound Images in Augmented Reality. IEEE Ultrasonics, Ferroelectrics, and Frequency Control Joint Symposium (UFFC-JS 2024), IEEE UFFC Society, Sep 2024, Taipei, Taiwan. hal-04671751

HAL Id: hal-04671751

<https://hal.science/hal-04671751v1>

Submitted on 27 Jan 2025

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A Framework for Real-Time Visualization of Experimental and Simulated Ultrasound Images in Augmented Reality

François Gaits¹, Gauthier Bouyjou¹, Fabien Vidal², Enrico Boni³, Alessandro Ramalli³, Piero Tortoli³, Adrian Basarab⁴, and Nicolas Mellado¹

¹Institut de Recherche en Informatique de Toulouse, UMR CNRS 5505, Université de Toulouse, France

²Department of gynecologic surgery, Clinique Croix du Sud Ramsey Santé, Quint Fonsegrives, France

³Department of Information Engineering, University of Florence, Florence, Italy

⁴Université de Lyon, Université Claude Bernard Lyon 1, INSA-Lyon CNRS, Inserm, CREATIS UMR 5220, U1206, Villeurbanne, France

Abstract—2D ultrasound imaging has many advantages, among which ease-of-use, low cost and non-ionizing nature. However, in several applications, its operability is limited and requires in-depth knowledge and/or operator experience. This paper presents an augmented reality framework that inscribes itself in the standard workflow of ultrasound imaging. By using a flexible architecture, the proposed framework alleviates tasks such as medical procedures, practician training or dataset creation. This article showcases the framework through three applications, experimental images visualization, interactive simulated image generation and pre-operative 3-D reconstruction.

Index Terms—Ultrasound imaging, Augmented reality, 3-D reconstruction, Ultrasound simulation

I. INTRODUCTION

Ultrasound imaging is widely employed in various medical applications due to its non-ionizing nature, real-time capabilities, and cost-effectiveness.

However, many ultrasound procedures, such as cardiac catheterization, nerve blocks or tumor resection, demand the simultaneous use of both hands for device manipulation and continuous observation of the monitor. Dividing attention between managing the equipment and interpreting the images in real time can potentially affect the accuracy and efficiency of the procedure, rendering the task arduous, especially for young or in-training practitioners [1].

To address these challenges, we propose a framework that integrates ultrasound imaging with augmented reality (AR) technology. This approach allows operators to visualize ultrasound images directly within their field of view, eliminating the need to constantly shift focus between the monitor and the patient.

In addition to the AR integration, the proposed framework supports the creation of comprehensive datasets for use in various scenarios and with different processing methods. This adaptability enables the system to be applied across a wide range of clinical procedures, offering enhanced flexibility and

potential for further development in ultrasound-based diagnostics and interventions.

AR technology has gained widespread use in various fields, particularly in supporting complex procedures and training [2]. In the medical field, it has been demonstrated that AR can improve the efficiency of clinical tasks by providing real-time overlays of crucial information [3]. AR can also enhance diagnostic processes [4], [5], especially when paired with ultrasound imaging [6]. Moreover, AR plays a key role in medical education, offering immersive training experiences that allow practitioners to simulate and practice complex procedures in a controlled environment [1], [2].

The challenge of acquiring and utilizing datasets for research in ultrasound imaging is long-standing. Frameworks like Stradx [7] were developed to facilitate the acquisition of spatially-referenced ultrasound images for use in 3-D reconstruction algorithms. However, these systems often face challenges with synchronizing the outputs of closed-box ultrasound imaging machines with their positioning systems. In a related effort, in 2009, Tortoli *et al.* [8] introduced ULA-OP, an echographic system providing open access to acquired data, specifically designed to support research and the development of new ultrasound methodologies.

The AR framework presented in this work aims at mitigating some of the challenging issues mentioned above. More precisely, this framework is able to (i) display ultrasound images in real-time at the emplacement of their acquisition, overlaid with the real world, (ii) acquire and export datasets containing the images and their position for further use, and (iii) display features computed from these datasets, such as 3-D volume reconstructions, at the correct location.

II. MATERIAL AND METHODS

The framework presented in this article is a system able to incorporate multiple sensors, acquisition devices and computation results in an AR environment to respond to diverse

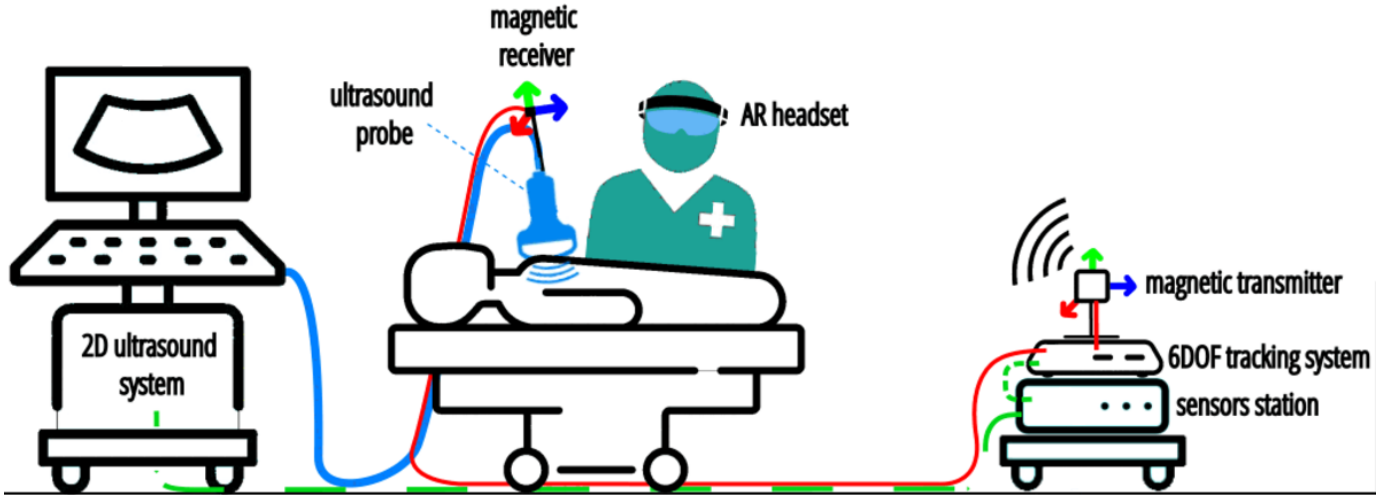


Fig. 1. Overview of the AR framework. A probe is connected to an ultrasound system, or replaced by a mock ultrasound probe and 3-D trackers are attached to the probe and the AR headset, allowing for global repositioning.

needs of ultrasound imaging. An overview of the framework is illustrated in Figure 1 in the case of the direct, *in-situ*, visualization of ultrasound images.

In this framework, several sensors may be integrated and work together to achieve the desired application. In the applications presented in this work, a probe and an ultrasound system (here ULA-OP [8]) provide precisely timed ultrasound images to the AR headset (here a HoloLens 2 [9]). All these sensors are 3-D tracked and repositioned in the same coordinate system to provide a clear and coherent visualization. Figure 2 presents the main tools used in this work.



Fig. 2. Material used in the framework. ULA-OP [8] research platform (top left), 3-D tracked AR headset (bottom left), mock ultrasound probe (middle) and ultrasound probe (right)

From an architecture standpoint, the framework respects a standard client-server scheme. The server is a central computer, referred to as the hub, overseeing the operations and the coordination among sensors. The clients are distributed between two categories: streamers and viewers. Streamers are sensors providing the hub with information such as the ultrasound system or position sensors. Viewers are display devices

receiving information from the hub. The main one is the AR headset, but multiple viewers may be used for visualization, allowing multiple AR display, or monitoring through a 3-D viewer on a connected computer. This architecture is illustrated in Figure 3.

The use of a central hub allows many complex applications. By deporting the load of computations from the headset to the hub and using the viewers only as display systems, heavy operations, such as 3-D volume reconstruction, image transformation or synchronization, may be efficiently performed.

Synchronization of the acquisitions with the position sensors is one of the key components, as the accuracy of the relative positions of the data is crucial for the direct display as well as further exploitation. In our framework, the ultrasound data is precisely timestamped even before B-mode image formation, thanks to the ULA-OP software [10]. To further improve the precision, the registered positions are then interpolated to perfectly match the timestamp of other acquisitions, as performed in [7], ensuring perfect coupling of data and position even for lower refresh rate sensors.

III. APPLICATIONS

In this section, we highlight the framework abilities and versatility by presenting three different applications: direct visualization of ultrasound images, interactive ultrasound simulation display, and *in-situ* visualization of reconstructed 3-D ultrasound volume.

A. *In-situ* visualization of ultrasound images

The first application of the proposed framework is to overlay experimental ultrasound images at the location of their acquisition. Figure 4 shows this application on a nerve block phantom, displaying clearly the nerve structure in the image over the location of the nerves, allowing the visualization of both the image and the medium.

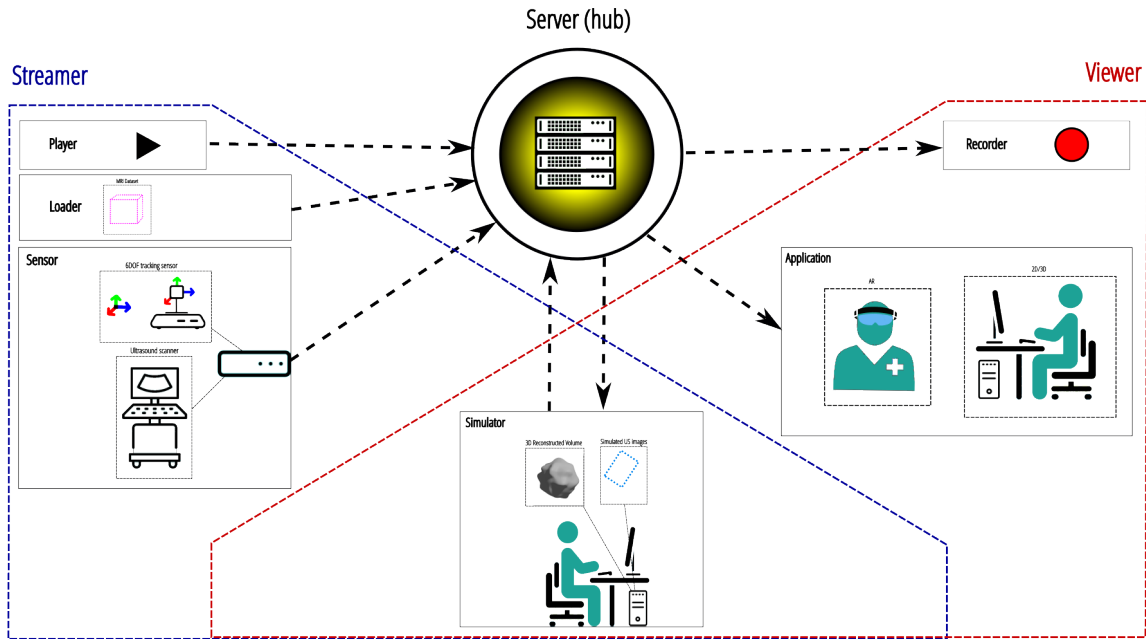


Fig. 3. System architecture of the framework. A main server (hub) communicates with several clients, ensuring coordination and data access.

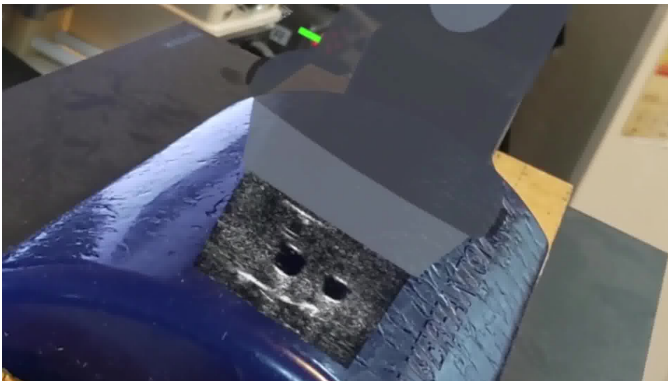


Fig. 4. Visualization of an ultrasound acquisition *in-situ* through AR.

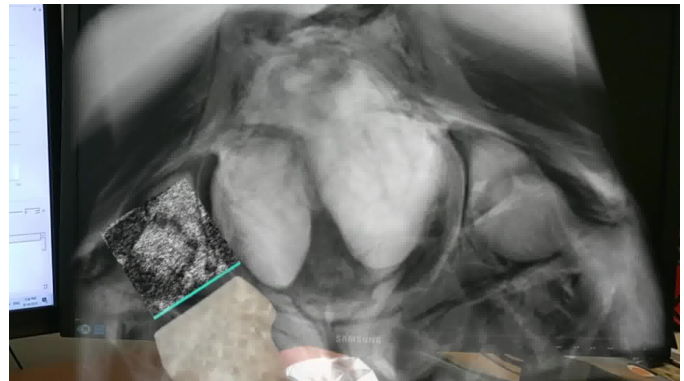


Fig. 5. Simulation of an ultrasound image under the mock probe with a pelvic MRI as a base.

Using this application has two main advantages. First, a practitioner is able to ultrasound guided procedures without looking at both a monitor and the actual procedure site and can directly link action and their visualization (i.e. insertion of a needle and its apparition on the ultrasound image, injections, etc). Second, the acquired images and their positions can be recorded and exported for further exploitation.

B. Interactive ultrasound simulation display

In this application, the real medium is replaced with a virtual one, corresponding to 3-D data, such as medical data (e.g., MRI, CT scans) or 3-D models. This 3-D data is used to simulate the appearance of ultrasound images with respect to a mock probe position and display it in real-time. In Figure 5 this application is illustrated with a pelvic MRI.

The ultrasound images are simulated following the procedure described in [11]. Using a stratification strategy, a

constant set of 3-D scatterers is generated over the whole medium and extracted in real-time to serve as in traditional 2-D ultrasound simulators, guaranteeing consistent temporal and spatial noise as well as respect of the physical and statistical properties of ultrasound imaging. The computation of simulated images is performed on the hub and then sent to the viewers, yielding more than 20 frames per second.

This application alleviates the need of both a real medium and an ultrasound system. it can thus be used for education and training purposes in a simple setup. This allows the realization of complex scenarios and controlled situations in a safe environment. Furthermore, as with the experimental images, those acquisitions can be saved as datasets. Due to the flexible nature of the simulation, those datasets can be very varied, and are always associated with the base for the simulation, providing access to a ground truth.

C. In-situ ultrasound 3-D volume

The data acquired following the two previous applications can be used through the client-server architecture to perform heavy computations on the hub subsequently display the results. To illustrate this, this application uses a dataset acquired as explained in Section III.A to reconstruct the 3-D volume and isolate the structure of interest. Figure 6 represents the result of the computation overlaid with the used dataset, effectively showing the internal structure of the phantom.



Fig. 6. 3-D volume reconstruction placed over the acquisitions' location, accurately representing the underlying medium.

Once the data is sent to the hub, the volume is computed in a few tens of seconds using an improved version of [12]. In this method, an unsupervised, randomly initiated and lightweight neural network learns the association between the 3-D coordinates of the pixel and their value, generalizing over the whole volume of interest in the process. This network is then used as a function $\mathbb{R}^3 \rightarrow \mathbb{R}$. In Figure 6, an isosurface has been handpicked to represent the structure of interest.

Using this application allows the practitioner to observe the volume in its entirety without having to manipulate the probe anymore. This can be used to perform hand-free interventions, needle insertions or any operation that would otherwise require both ultrasound monitoring and practitioner manipulation. Furthermore, this application puts forward the capacity of the framework to integrate procedures in the same time frame without computational limitations, paving the way to a wide area of possibilities.

IV. CONCLUSION

In this paper, we have demonstrated the use of an AR framework that responds to common challenges of ultrasound imaging, such as operability during medical procedures or data acquisition. By adopting a flexible client-server architecture, this framework is able to evolve and adapt to many scenarios and perform the large computations required. Many more lanes might be explored in the future thanks to this framework, such as remote operations, cooperative work and formation, or integration of more tools, such as 3-D probes, LIDARs or other display systems.

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