Coherent Multi-Transducer Ultrasound Imaging with Micro-Bubble Contrast Agents

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***Abstract*—A coherent multi-transducer ultrasound imaging system (CoMTUS) enables an extended effective aperture through coherent combination of multiple transducers. The resulting larger effective aperture improves the ultrasound imaging performance. The optimal beamforming parameters, which include the transducer locations and the average speed of sound in the medium, are deduced by maximizing the coherence of the received radio frequency data by cross-correlation. In this technique, the detection of multiple isolated point-like targets in the overlap of the insonated regions is mandatory to determine the relative probe-to-probe position. This study proposes the use of microbubbles to generate the point-like targets that the CoMTUS approach requires. The first phantom images produced using CoMTUS and microbubbles are presented here.**

***Index Terms*—Ultrasound Imaging, Plane Waves, Large Aperture, Microbubbles, Multi-transducers**

I. Introduction

The quality of ultrasound images is often limited by the spatial resolution and restricted field of view (FoV), particularly at large depths in abdominal or fetal imaging applications [1]. Transducers with a larger aperture size are desirable in ultrasound imaging to improve resolution and image quality. Recently, we have developed a coherent multi-transducer ultrasound imaging system (CoMTUS) [2]–[4] that allows the use of multiple ultrasound arrays as one large effective aperture, improving the ultrasound imaging performance. To coherently combine all radio frequency (RF) data received by the multiple probes, CoMTUS optimizes the beamforming parameters. These optimal beamforming parameters, which include the transducer locations and the average speed of sound in the medium, are deduced by maximizing the coherence of the received RF data resulting from different targeted scatterer points in the medium. Hence, it is mandatory for the method to detect the existence of multiple (at least 2) isolated point-like targets within the common imaging region of the probes [2].

However, in practice the complex and dense scattering environment typically found in the body might limit the success of the approach because the presence of detectable and isolated point scatterers may not be always possible. Nevertheless, they can be artificially generated by other techniques, for instance, by the inclusion of microbubble (MB) contrast agents. Ultrasound super-resolution imaging has demonstrated that spatially isolated individual MBs can be considered similar to point scatterers in the acoustic field and accurately localized [5]–[9]. This study proposes the use of MBs to generate the point-like targets that CoMTUS requires.

II. Methods

The feasibility of MBs as reference points to localise multiple transducers with enough precision to coherently increase the effective aperture of the imaging system was experimentally investigated. The proposed methodology is summarized in Figure 1 and consists of 5 steps: (1) RF data acquisition by 2 synchronised imaging systems; (2) registration of images acquired by the 2 imaging systems to obtain the initial estimation of CoMTUS beamforming parameters; (3) MB detection and localisation; (4) optimization of CoMTUS beamforming parameters; and (5) CoMTUS beamformation.

A. Experimental Setup and Data Acquisition

A cylindrical agar-based phantom was immersed in a water tank containing a dilute suspension of Sonovue (Bracco, Milan) MBs (40 μl SonoVue in 2.2 l water). The MB suspension was stirred to ensure a uniform distribution within the FoV. The imaging setup consists of two synchronised 256-channel Ultrasound Advanced Open Platform (ULA-OP 256) systems (University of Florence, Italy) [10], [11] and two identical ultrasonic linear arrays (LA332, Esaote Italy). The two probes were mounted on a multi-probe holder physical device to maintain them on the same imaging plane (y = 0) [12]. The

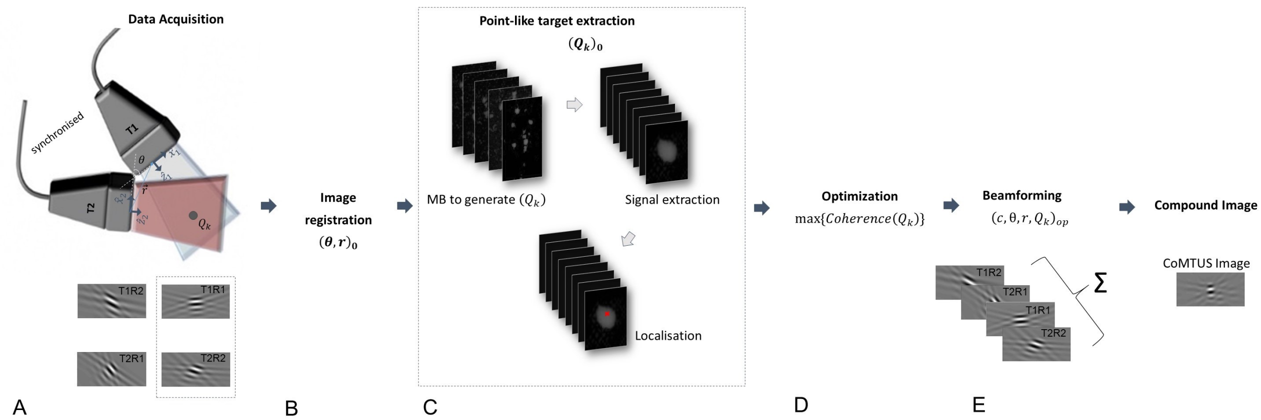

Fig. 1. Schematic diagram of the methods. A. Data is acquired using alternating PW transmission from probe 1 and 2 (T1, T2) and simultaneously receive (R1, R2). B. Images are first registered to obtain initial estimation of beamforming parameters. C. Microbubbles in common field of view are detected and localized using ultrasound super-resolution methods. D. By optimizing the coherence between backscattered echoes from localized microbubbles, optimum beamforming parameters are calculated. E. A final image is reconstructed with these parameters.

phantom was placed within the imaging plane of both arrays. The experimental sequence starts with probe 1 transmitting a PW at 3 MHz and pulse repetition frequency (PRF) of 7 kHz into the common FoV. Then, the backscattered ultrasound field is simultaneously acquired by both transducers at a sampling frequency of 19.5 MHz. This sequence is repeated but transmitting with probe 2 and again recording the backscattered echoes with both transducers. Since every transmitted PW is received by both probes, including the transmitting one, the experimental sequence yields four RF datasets in total. Using this sequence, RF data of the ultrasound phantom immersed in the MB suspension was acquired over 3 minutes.

Two single images, acquired by each of the imaging systems, were first beamformed following the standard delay and sum method for PW imaging [13]. Then, using point-based image registration [14], the spatial position of probe 2 relative to probe 1 was calculated. Finally, the location in space of both probes, along with the speed of sound in water (assumed 1496 m/s), lead to the initial estimate of the beamforming parameters. These are needed to start the optimization algorithm in CoMTUS as described in [2].

B. Microbubble Localization

Microbubbles present in the common FoV of both transducers were detected and localised through a similar approach to that in ultrasound super-resolution imaging [8]. A rolling background subtraction was firstly applied to images, and bubble signals were detected by comparing connected regions in the foreground to the expected size of point scatterers in the image. Bubbles were then localized by calculating the intensity-weighted centre of mass of each detected region. Bubble localizations from both transducer FoVs were then used as inputs to the coherent multi-transducer ultrasound imaging method.

C. Coherent-Multi Transducer Ultrasound Imaging

CoMTUS extends the effective aperture size of the imaging system by coherently compounding the received RF data from multiple transducers. To provide precise relative positioning information of the different transducers so that they might be used as one coherent whole, the method is based on the mutual information available in the signals received by the individual transducers [2]–[4].

In this work, for each sequence, the CoMTUS optimum beamforming parameters, which include array locations in space and average speed of sound in the medium, were calculated by maximizing the cross-correlation of backscattered signals from common MBs, previously localized, and acquired by individual receive elements, by using gradient-based optimization methods. Then, the multi-probe beamformation was performed using the standard delay and sum method for PW imaging [13] and taking into account the full path length between the transmit array and the receive elements, precisely defined by the optimum beamforming parameters. Finally, a CoMTUS image was obtained by coherently adding the totality of the RF data acquired in one sequence, i.e. 4 RF datasets in total generated by alternately transmitting from probe 1 and 2 and simultaneously receiving.

Resulting CoMTUS images were compared with the equivalent images acquired by a single probe. Lateral resolution (LR), contrast and contrast-to-noise ratio (CNR) were measured in all cases.

III. Results

Figure 2 shows a comparison between an image acquired with a single probe and a CoMTUS image. Overall, it is observed there is an improvement in the CoMTUS image. Table I summarizes the imaging metrics of all approaches, i.e. imaging using a single probe and CoMTUS. Both contrast

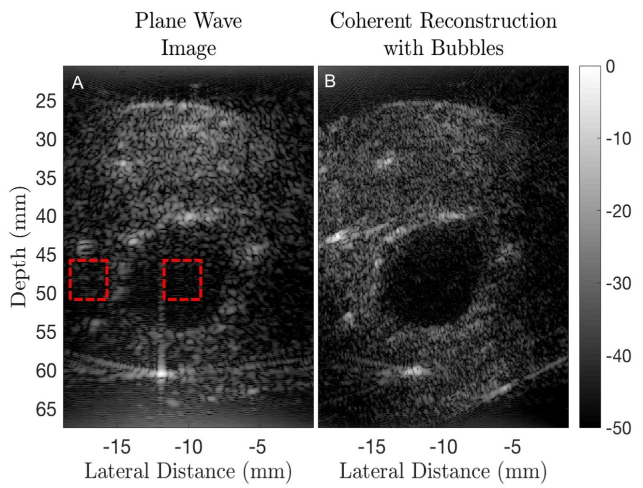

Fig. 2. Comparison of resulting images. A. Single probe image using PWs. B. CoMTUS image using MB localizations. Contrast measurements taken from regions of interest inside and outside phantom inclusion (red regions in A).

and lateral resolution improved using the CoMTUS method with MB, from -3.1 dB to -12.7 dB and from 1.14 mm to 0.49 mm, respectively.

TABLE I
EXPERIMENTAL IMAGING METRICS

Imaging method	Lateral Resolution [mm]	Contrast [dB]	CNR [-]
1-probe	1.06 ± 0.12	-3.1	0.45
CoMTUS	0.49 ± 0.11	-12.7	1.07

Preliminary results show the potential of MB to optimize the beamforming parameters in CoMTUS, which could be implemented in-vivo wherever the FoV contains vasculature. Furthermore, this provides potential for CoMTUS to be generated with corresponding ultrasound super-resolution, providing both enhanced tissue and vascular information.

IV. Conclusions

This study investigates the use of microbubbles to generate the point-like targets that CoMTUS requires. The method was experimentally validated in ultrasound phantoms. Results show that MBs can be used in CoMTUS to optimize the beamforming parameters. The use of MB will allow implementation of CoMTUS in-vivo wherever the FoV contains vasculature.

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