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Plane-Wave Imaging Challenge in Medical Ultrasound

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Abstract— Plane-Wave imaging enables very high frame rates, up to several thousand frames per second. Unfortunately the lack of transmit focusing leads to reduced image quality, both in terms of resolution and contrast. Recently, numerous beamforming techniques have been proposed to compensate for this effect, but comparing the different methods is difficult due to the lack of appropriate tools. PICMUS, the Plane-Wave Imaging Challenge in Medical Ultrasound aims to provide these tools. This paper describes the PICMUS challenge, its motivation, implementation, and metrics.

Keywords—ultrasound, challenge, Plane-Wave, beamforming, ultrafast.

I. INTRODUCTION

Researchers and engineers in the field of medical ultrasound have always tried to improve image quality and frame rates. This was already the objective with synthetic aperture imaging (STA) [1]. More recently, our domain has undergone a revolution with the emergence of Plane-Wave Imaging (PWI), which has been applied to most fields in medical ultrasound [2] yielding framerates as high as several thousands of images per second. At first this increase in framerate was obtained at the expense of reduced contrast and resolution. However, this drawback was skilfully addressed by Coherent Plane-Wave Compounding (CPWC) [3], which introduced a trade-off between framerate and image quality. Note that compounding is also used in STA.

Beamforming has therefore regained a lot of its past attention, with the proposal of numerous beamforming techniques that aim to increase image quality without losing framerate. In addition, some design choices can have a significant impact on the resulting quality, such as the choice of the steering angles, apodization, or probe design. On the other hand, more sophisticated techniques often come at the cost of increased processing time or computing power, which may hinder real-time operation with state-of-the-art technology.

Unfortunately most of the proposed techniques are only compared to delay-and-sum. In some selected cases new methods are tested against other contemporary techniques, but understandably, the amount of time and fine tuning devoted to

these auxiliary implementations is rarely the same as used for the proposed method. In addition, the testing conditions vary from paper to paper (simulation and experimental parameters, probe and scanner settings, imaged medium, etc.), which makes it even more difficult to generalize the results. Finally the metrics used for the assessment of image quality can also vary from one study to other. Altogether, this makes plane-wave imaging a good topic for a research challenge with a consistent set of performance metrics.

Challenges are regularly organized and hosted by medical imaging conferences like IEEE International Symposium on Biomedical Imaging [<http://biomedicalimaging.org/2016/>] or Medical Image Computing and Computer Assisted Intervention MICCAI [<http://www.miccai2016.org/en/>]. The idea is to provide to the participants a number of datasets to be processed by their method. The results are then uploaded to a web platform and evaluated with a set of predefined metrics. So the methods can be objectively compared.

For the first time in history a challenge is organized by the IEEE International Ultrasonics Symposium, to be held in Tours, France the 21 September of 2016. In the remaining we describe the design and implementation of the first edition of the Plane-Wave Imaging Challenge in Medical Ultrasound (PICMUS).

II. PICMUS

The aim of PICMUS is to provide the community with a tool to objectively compare newly proposed beamforming methods. The challenge includes:

- a website with all available information,
- the challenge platform (MIDAS),
- two simulated CPWC datasets in HDF5 format,
- two experimental CPWC datasets in HDF5 format,
- example code, in MATLAB, on how to interact with the datasets, and
- tests for contrast, resolution, geometrical distortion, and speckle appearance.

These features are further described in the following sections.

Description of the datasets

PICMUS has been designed for PWI and CPWC beamforming techniques. Other beam shapes, such as focused beams, diverging waves, and synthetic transmit aperture are not included.

Each dataset contains 75 steered Plane-Waves covering the angle span from -16° to 16° . Each dataset is available in RF (modulated) and IQ (demodulated) format. The dataset were stored in HDF5 (Hierarchical Data Format).

Two datasets were generated with Field II [4, 5]. The parameters used in the simulation, shown in Table 1, were fine tuned to correspond as much as possible to the experimental setup. A first dataset consisted of isolated scatterers distributed vertically and horizontally over an anechoic background (see Figure 3a). A second simulated dataset included a number of anechoic cysts, also distributed vertically and horizontally, over fully developed speckle (see Figure 3c).

Table 1: Imaging parameters used both in simulations and for the experiments

Pitch	0.30 mm
Element width	0.27 mm
Element height	5 mm
Elevation focus	20 mm
Number of elements	128
Aperture width	38.4 mm
Transmit frequency	5.208 MHz
Sampling frequency	20.832 MHz
Pulse bandwidth	67%
Excitation	2.5 cycles

Two experimental datasets were provided. Data were acquired using a Verasonics Vantage 256 research scanner and a L11 probe (Verasonics Inc., Redmond, WA). The datasets were recorded on a CIRS Multi-Purpose Ultrasound Phantom (Model 040GSE) in the regions indicated in Figure 1. A first dataset contained several wires against speckle background (see Figure 3b). A second dataset contained two anechoic cysts against speckle background (see Figure 3d).

Besides, a collection of MATLAB classes were provided to the participants specifying how to interact with the datasets, together with a reference implementation of delay-and-sum (DAS) beamforming. The participants were then asked to beamform the four datasets on a specific grid of points, and to supply the envelope image before any kind of compression.

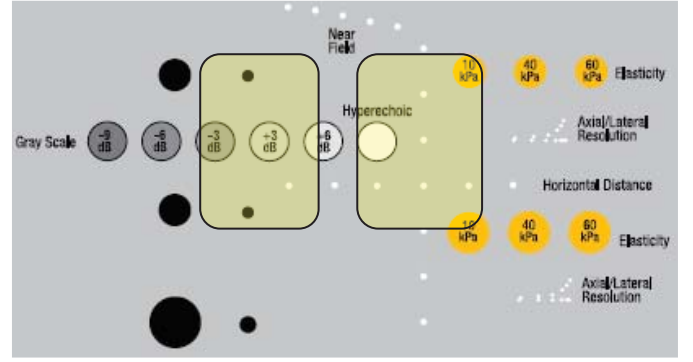


Figure 1 Schematic of the upper part of the CIRS Model 040GSE Phantom used for the experiments. The highlighted left region was acquired for contrast evaluation and the right region for resolution evaluation.

Description of the metrics

Contrast and resolution are, by far, the most used metrics to assess image quality. But it is also important to check for geometrical distortion and good speckle statistics.

To estimate resolution the full width at half maximum (FWHM) was evaluated both in axial and lateral directions. The FWHM obtained for all scatterers in the image were averaged to obtain the average axial and lateral resolution in both simulations and experiments (Figures 3a and 3c).

Contrast was estimated with the classical expression for contrast to noise ratio (CNR),

$$CNR = 20 \log_{10} \left(\frac{|\mu_{in} - \mu_{out}|}{\sqrt{(\sigma_{in}^2 + \sigma_{out}^2) / 2}} \right) \quad (1)$$

where μ_{in} and μ_{out} are the mean gray level inside and outside the anechoic cystic region, and σ_{in} and σ_{out} are the gray level standard deviation inside and outside the anechoic cystic region. As for the resolution, the CNR for all the cysts in the image were averaged leading to one CNR for the simulations and one for the experiments (Figures 3b and 3d).

Geometrical accuracy was verified by investigating the position of the points scatterers (Figures 3a and 3c). For the simulations the true position of the scatterers was used as reference. For the experiments, the provided DAS implementation was used as reference. Geometrical distortion was penalized if the maximum distance of any scatterer from its theoretical position was greater than one wavelength.

Considering that speckle is an intrinsic characteristic of ultrasound images, it was decided to penalize methods that removed speckle. It is well-know that the intensity of fully developed speckle follows a Rayleigh distribution. For a set of predefined regions, the Kolmogorov–Smirnov (KS) test was applied. The speckle quality test was considered positive, if the tested regions obtained a significance level $\alpha = 0.05$ in the KS test.

Description of the competition and the ranking

Research challenges are inherently competitive. Healthy competition has proven itself as a robust and reliable way to drive research and spur discussion. To achieve this it is necessary to combine the metrics into a single value, so that participants can be ranked. Yet, the direct comparison and discussion of the individual metrics is, most probably, of more scientific value.

Four categories have been set depending on the number of plane-wave selected by the participants

- Category I: 1 plane-waves,
- Category II: 11 plane-waves,
- Category III: 75 plane-waves,
- Category IV: arbitrary number of plane-waves.

In all categories, except in category III which uses all of them, the angles can be chosen arbitrarily. In category IV the score is normalized by the number of Plane-Waves used with the following expression

$$final_score = \sum_{all_metrics} \left(\frac{pts}{1 + \frac{NB}{5}} \right) \quad (2)$$

where NB is the number of Plane-Waves used by the participant and *pts* is the number of points received by the participants for a given metric.

Material available

All the information is available at the website https://www.creatis.insa-lyon.fr/Challenge/IEEE_IUS_2016/. It describes the datasets, the metrics, provides a link to the data and the code, as well as some more general information about the organization of the challenge.

Participants get access to the challenge through the web platform http://challenge.creatis.insa-lyon.fr/IEEE_IUS_2016/community/1#tabs-info. It is the intention of the organisers to maintain the platform as long as possible and even keep extending it in the future to support comparison with other methods after the challenge.

The platform includes a collection of Matlab classes that facilitate the interaction with the HDF5 dataset and illustrate how the metrics are calculated.

III. EXAMPLES

Figure 2 (respectively Figure 3) shows the images obtained with the DAS method provided as reference, when a single 0 degrees plane-wave is transmitted (respectively when the 75 transmitted plane-waves are combined). The two Figures show images of the four provided datasets. From left to right Figure 2 and Figure 3 show first the two images used for resolution evaluation in simulations and experiments, and then the two images used for contrast evaluation in simulations and experiments. As expected using 75 plan-waves leads to better contrast and resolution both in simulations and experimentally.

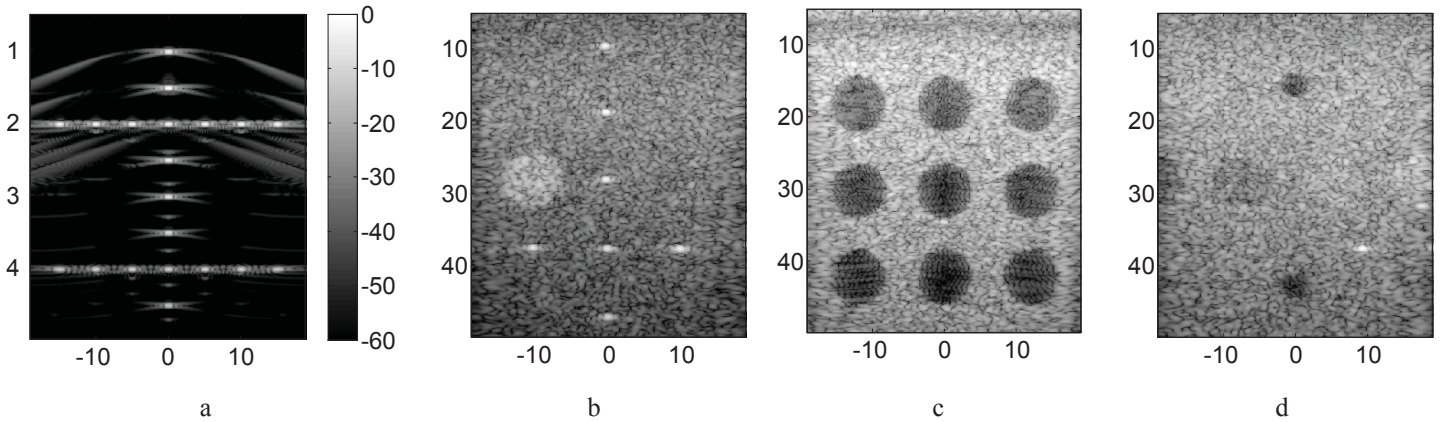


Figure 2 Example of simulated (a and c) and experimental (b and d) images obtained with the DAS provided within PICMUS for the resolution (a and b) and contrast (c and d) images with only one Plane-Wave. Axial and lateral dimensions are given in mm, and the grey scale ranges from -60 to 0dB.

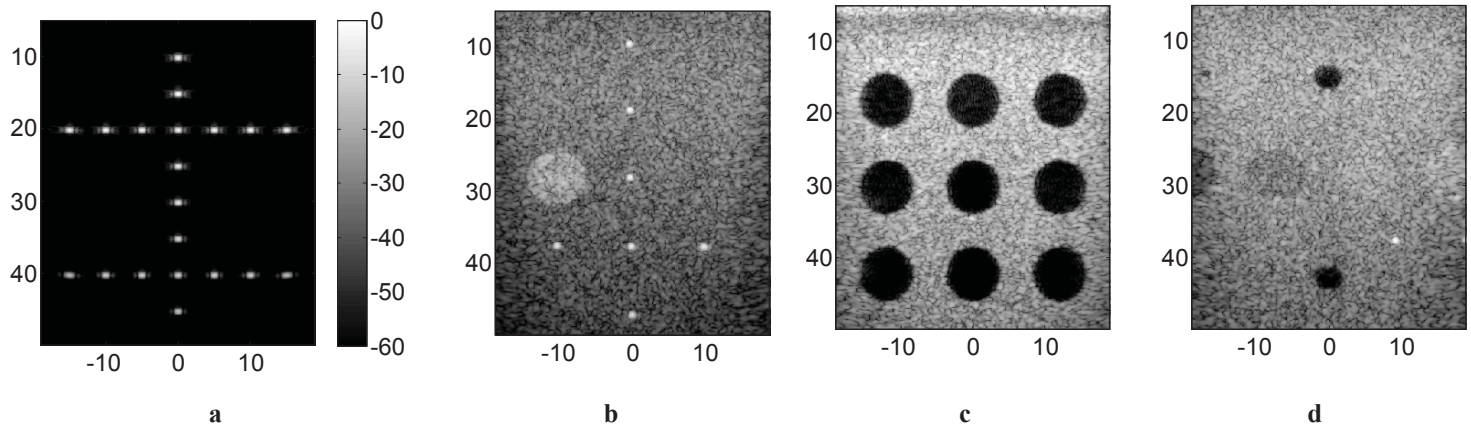


Figure 3 Example of simulated (a and c) and experimental (b and d) images obtained with the DAS provided within PICMUS for the resolution (a and b) and contrast images (c and d) with all 75 Plane-Waves. Axial and lateral dimensions are given in mm, and the grey scale ranges from -60 to 0dB.

IV. DISCUSSION AND CONCLUSION

PICMUS is a tool to assess the relevance of new beamforming methods and compare their performance with other state-of-the-art methods in an objective and standardized way.

Unfortunately, due to practical reasons and several time constraints, the scope of PICMUS was limited.

First of all the choice has been made to consider only plane wave imaging. Other transmit strategies could also be interesting topics for a challenge, like for example synthetic aperture imaging. Also transmit apodization could have been considered.

For instance, only static phantoms were considered. Motion artefacts can dramatically affect the images quality of fast moving objects. When motion is considered not only the number of transmitted angles is important, but also the order in which they have been transmitted.

Phase aberration was not covered by the provided datasets. This could be easily included, both in simulations and experimentally, by adding a phase aberration layer on top of the phantoms introducing a small error in the phase. Equally simple would have been to evaluate how sensitive the methods were to sound speed errors.

Also PICMUS does not take into account the processing time, which might be decisive in the assessment of the methods applicability. One way of including this metric would be to ask the participants to upload and run their code on the same online platform. However, in some cases intellectual property issues may have to be addressed. In addition, implementation in different language codes, or architectures (for instance GPU vs CPU based) may hinder a comparison of the algorithm's computation complexity.

In this first edition of the challenge we opted for a reduced scope for the sake of clarity and conciseness. But future editions could increase the scope and improve the metrics.

We believe utterly important to maintain the platform in time, open for other users to use and contribute, supporting the

objective intercomparison of methods and promoting fruitful discussion on the relevance of new ideas.

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