OPEN PLATFORM FOR ULTRASOUND LOCALIZATION MICROSCOPY: PERFORMANCE ASSESSMENT OF LOCALIZATION ALGORITHMS

AUTHORS: Arthur Chavignon, Baptiste Heiles, Vincent Hingot. CNRS, Sorbonne Universite, INSERM.
Directed by: Olivier Couture, Research Director CNRS, Sorbonne Université, INSERM
Laboratoire d'Imagerie Biomédicale, Team PPM. 15 rue de l'Ecole de Médecine, 75006, Paris, France
Code Available under Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International (see https://creativecommons.org/licenses/by-nc-sa/4.0/)
Partly funded by the European Research Council under the European Union Horizon H2020 programme/ERC Consolidator grant agreement No 772786-ResolveStroke

ACADEMIC REFERENCES TO BE CITED

Details of the code in the article by Heiles, Chavignon, Hingot, Lopez, Teston and Couture.
Performance benchmarking of microbubble-localization algorithms for ultrasound localization microscopy, Nature Biomedical Engineering, 2021.

General description of super-resolution in: Couture et al., *Ultrasound localization microscopy and super-resolution: A state of the art*, IEEE UFFC 2018.

CORRESPONDING AUTHORS

Article: Baptiste Heiles, baptiste.heiles@gmail.com
Materials, scripts, and codes: Arthur Chavignon, arthur.chavignon.pro@gmail.com
Collaborations, rights and others: Olivier Couture, olivier.couture@sorbonne-universite.fr

ABSTRACT

Ultrasound Localization Microscopy (ULM) is an ultrasound imaging technique that relies on the acoustic response of sub-wavelength ultrasound scatterers to map the microcirculation with an order of magnitude increase in resolution. Initially demonstrated in vitro, this technique has matured and sees implementation in vivo for vascular imaging of organs, and tumors in both animal models and humans. The performance of the localization algorithm greatly defines the quality of vascular mapping. We compiled and implemented a collection of ultrasound localization algorithms and devised three datasets in silico and in vivo to compare their performance through 11 metrics. We also present two novel algorithms designed to increase speed and performance. By openly providing a complete package to perform ULM with the algorithms, the datasets used, and the metrics, we aim to give researchers a tool to identify the optimal localization algorithm for their usage, benchmark their software and enhance the overall image quality in the field while uncovering its limits.

1. DATA and MATERIALS PROVIDED

In addition to this publication, we provide all datasets, scripts and functions for this publication. Files and folders have been split into various compressed files (`.zip`) to facilitate downloading. All compressed files must be uncompressed in the same folder (for example `D:\PALA_test\`), and data folders will be automatically merge (`DataFolder_part1.zip` and `DataFolder_part2.zip` will be merge into folder `DataFolder\`). Before running scripts (available in github.com/AChavignon/PALA), the `PALA_addons_folder` and `PALA_data_folder` must be specified in `PALA\PALA_scripts\PALA_SetUpPaths.m`. (See README on GitHub)

2. Package `PALA_data_InSilicoPSF` (`PALA_data_InSilicoPSF.zip`)

This folder contains materials related to the *In Silico PSF* dataset:

- `PALA_InSilicoPSF_IQ001.mat` : 1400 frames of a simulated scatterer in the center of the image, with a random shift.
- `PALA_InSilicoPSF_RF001.mat` : associated radiofrequency data related to the 1400 IQ frames.
- `PALA_InSilicoPSF_sequence.mat` : ultrasound sequence associated to simulation of 1400 frames.
- `PALA_InSilicoPSF_LocalMesh30dB.mat` : results of the 7 localization algorithms with a clutter noise of 30dB.
- `PALA_InSilicoPSF_scores.mat` : final results before conversion into indexes for the global score.

3. Package `PALA_data_InSilicoFlow` (`PALA_data_InSilicoFlow.zip` and `PALA_data_InSilicoFlow_RF.zip`)

This folder contains materials related to the *In Silico Flow* dataset:

- `PALA_InSilicoFlow_sequence.mat` : ultrasound sequence associated to simulation with all parameters.
- `PALA_InSilicoFlow_v3_config.mat` : configuration files with main parameters, and the simulated density image.
- `PALA_InSilicoFlow_v3_pos_Tracks_ds.mat` : list of scatterers trajectories with curvilinear abscissa steps (used for density image).
- `PALA_InSilicoFlow_v3_pos_Tracks_dt.mat` : list of scatterers trajectories with a time step.
- `PALA_InSilicoFlow_scores.mat` : final results before conversion into indexes for the global score.
- `IQ/PALA_InSilicoFlow_IQ0xx.mat` : 20 files of 1000 simulated frames of the propagation of t scatterers inside canals.
- `RF/PALA_InSilicoFlow_RF0xx.mat` : associated radiofrequency data related to 1000 simulated frames.
- `Results/PALA_InSilicoFlow_Tracks_multi_xxdB.mat` : results of localization/tracking algorithms for the 7 algorithms, at SNR = {10;15;20;25;30;40;60} dB.
- `Results/PALA_InSilicoFlow_MatOut_multi_xxdB.mat` : associated Density images for the 7 algorithms at SNR = {10;15;20;25;30;40;60} dB.
- `Results/PALA_InSilicoFlow_Stats_multixxdB.mat` : results of pairing/rejection of microbubbles with the ground truth, for the 7 algorithms at SNR = {10;15;20;25;30;40;60} dB.

4. DATA Packages

All in vivo datasets have been compressed in various files.

1. *In Vivo Rat Brain* (`PALA_data_InVivoRatBrain_part1.zip` and `PALA_data_InVivoRatBrain_part2.zip`)

This folder contains materials related to the *In Vivo Rat Brain* dataset:

- `PALA_InVivoRatBrain_Sequence_param.mat` : main parameters for the ultrasound sequence.
- `PALA_InVivoRatBrain_scores.mat` : final results before conversion into indexes for the global score.
- `IQ/PALA_InVivoRatBrain_xxx.mat` : 240 files of 800 frames of the rat at 1kHz with microbubbles injection.
- `Results/PALA_InVivoRatBrain_MatOut_multi_nointerp.mat` : density images with non-interpolated tracks after processing 240 files of 800 frames, for 7 localization algorithms.
- `Results/PALA_InVivoRatBrain_MatOut_multi.mat` : density images with interpolated tracks after processing 240 blocks of 800 frames, for 7 localization algorithms.

2. *In Vivo Mouse Tumor* (`PALA_data_InVivoMouseTumor.zip`)

- `IQ\PALA_InVivoMouseTumor_xxx.mat` : 150 files of 200 frames of the mouse tumor with microbubbles injection.
- `Results\PALA_InVivoMouseTumor_MatOut_multi_nointerp.mat` : density images with non-interpolated tracks with 7 localization algorithms.
- `Results\PALA_InVivoMouseTumor_MatOut_multi.mat` : density images with interpolated tracks with 7 localization algorithms.

3. *In Vivo Rat Brain Bolus* (`PALA_data_InVivoRatBrainBolus_part1.zip` and `PALA_data_InVivoRatBrainBolus_part2.zip`)

- `IQ\InVivoRatBrainBolus_xxx.mat` : 213 files of 800 frames of the rat brain microbubbles boluses.
- `Results\InVivoRatBrainBolus_MatOut_multi_nointerp.mat` : density images with non-interpolated tracks with 7 localization algorithms.
- `Results\InVivoRatBrainBolus_MatOut_multi.mat` : density images with interpolated tracks with 7 localization algorithms.

4. *In Vivo Rat Kidney* (`PALA_data_InVivoRatKidney_part1.zip` and `PALA_data_InVivoRatKidney_part2.zip`)

- `IQ\InVivoRatKidney_xxx.mat` : 238 files of 720 frames of the rat kidney microbubbles injection.
- `Results\InVivoRatKidney_MatOut_multi_nointerp.mat` : Density images with non-interpolated tracks with 7 localization algorithms.
- `Results\InVivoRatKidney_MatOut_multi.mat` : Density images with interpolated tracks with 7 localization algorithms.

6. Package `PALA_scripts` (Online only)

This folder will be available on GitHub at github.com/AChavignon/PALA. List of all scripts and functions used for the analysis of all datasets. More informations are detailed in [PALA\README.md](PALA\README.md).

- `PALA/PALA_scripts` : for each datasets, two scripts are provided: the first one for ULM processing of data, and the second one for comparing results and building metrics.
- `PALA/PALA_addons/ULM_toolbox` : functions used for ULM processing (localization, tracking, rendering).
- `PALA/PALA_addons/PALA_functions` : functions used for performance assessment of localization algorithms (statistics, metrics, comparison).

7. DISCLAIMER

THIS SOFTWARE IS PROVIDED BY THE AUTHORS AND CONTRIBUTORS "AS IS" AND ANY EXPRESS OR IMPLIED WARRANTIES, INCLUDING, BUT NOT LIMITED TO, THE IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE ARE DISCLAIMED. IN NO EVENT SHALL THE AUTHORS AND CONTRIBUTORS BE LIABLE FOR ANY DIRECT, INDIRECT, INCIDENTAL, SPECIAL, EXEMPLARY, OR CONSEQUENTIAL DAMAGES (INCLUDING, BUT NOT LIMITED TO, PROCUREMENT OF SUBSTITUTE GOODS OR SERVICES; LOSS OF USE, DATA, OR PROFITS; OR BUSINESS INTERRUPTION) HOWEVER CAUSED AND ON ANY THEORY OF LIABILITY, WHETHER IN CONTRACT, STRICT LIABILITY, OR TORT (INCLUDING NEGLIGENCE OR OTHERWISE) ARISING IN ANY WAY OUT OF THE USE OF THIS SOFTWARE, EVEN IF ADVISED OF THE POSSIBILITY OF SUCH DAMAGE.