

Creanuis

User Manual

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Introduction

1.1 General overview

Creanuis is a tool that simulates nonlinear radio frequency (RF) ultrasound images. It is the combination of two specific tools. The former is a nonlinear ultrasound propagation simulator, that allows to compute the evolution of the fundamental and second-harmonic wave [1]. Then, using this field information, the corresponding nonlinear radio frequency (RF) image is beamformed [2]. The resulting RF image contains the fundamental evolution, but also the second harmonic one. The design of the nonlinear propagation simulator, which is a generalization of an angular spectrum method (GASM), allows considering media with an inhomogeneous coefficient of nonlinearity and the simulated field impacts the final RF image simulation. Efforts on the computation time have been made on the nonlinear field with a version of the software working on GPU (graphic processing unit) [3]. In the whole software, the x , y , and z axis correspond to the lateral, elevation and axial directions.

1.2 Software description

Creanuis has been designed in C/C++ in order to perform a quick simulation of the nonlinear propagation and of the RF images. An interface is proposed in Qt¹, but can also be disabled. In the GASM simulations, the Fourier transform are performed using the FFTW library² [4], or the cuFFT library³, when the GPU programming is used. Some accompanying files are proposed to load the simulated data with Matlab. The structures of the saved data are detailed hereafter and the image can also be loaded with another program as soon as an interpreter is designed.

2 Installation

2.1 Windows

On windows, the provide package install the various required exe and dll files. The vcredist_x86, if not present on the system, has also to be installed. During the installation of Creanuis, the path of the installation has to be change (**do not used Program Files/ directory**) because last windows operating system forbids to write in this directory. Additional Matlab files are given in the installation direction. Three folder are also generated where the Creanuis program is install and are required to correctly executing the software (input/, nlrf_file/, pressure_field/).

2.2 Linux (Fedora) distribution

On Fedora distribution, the tar.gz file has just to be extracted. Then, the program can directly be used. The same directories as in the Windows installation are created and required.

¹ <http://qt.nokia.com/products/>

² <http://www.fftw.org/>

³ <http://developer.nvidia.com/cuda-downloads>

2.3 Created folder

Three directories are created by the install files and are required in the same root direction. The input folder is used to save some user inputs. All the created **nonlinear radio frequency (nlrf)** images are saved in the nlrf_file folder. The field, the nonlinear coefficient map and the settings (if saved) are saved in the pressure_field folder.

3 Interface description

The interface is organized in four tabs describing the probe, the propagation medium, the simulator used to compute the propagation and the method used to beamform the RF image. Below them are settings where the user chooses the working directory and how verbose Creanuis is.

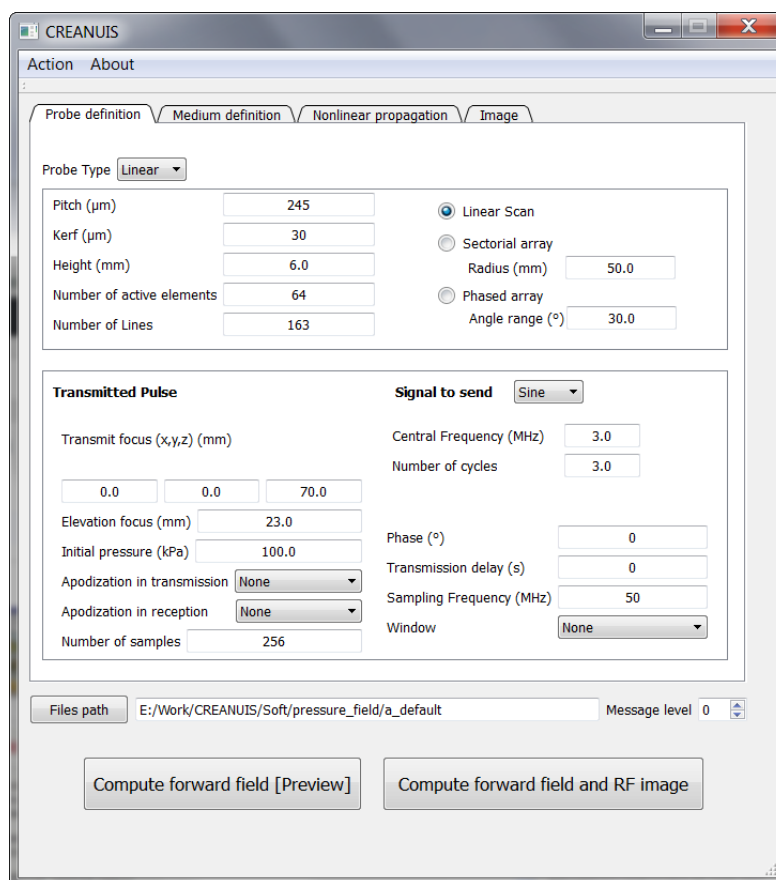


Fig. 1. General look of the interface

3.1 Toolbar and general settings

The toolbar is located at the top of the Creanuis window. The action menu enables to load or save the all the settings. The help menu displays a link to the Creanuis web site and the licence specification. The save/load actions save or load the data in the save_settings.txt file.



Fig.2. The Toolbar



Fig.3. The general setting

Two Creanuis settings are at the bottom of the window: the working directory and the message level. The user can define the path of the working directory of Creanuis. By default, this path is set to the directory where the Creanuis exe file is located, with the addition of the directory pressure_field/a_default. This path can be changed using the button “files path”. The message level number corresponds to the debug level wanted. If 0 is chosen, just some messages are displayed in the terminal. If 1 is selected, the debug messages corresponding to the RF image beamformed are displayed. With 2, the messages of the GASM simulation are also displayed.

3.2 Probe Settings

The first tab allows specifying the probe geometry, the pulse parameters and the beamforming configuration. Currently, only linear geometries are simulated with Creanuis which contained linear, sectorial or phased array arrays. In a future version of Creanuis, more complex arrays are going to be taken into account as 2D arrays. In the proposed version, 2D arrays are proposed but the image generation is not correctly working.

The screenshot shows the 'Probe definition' tab with the following settings:

- Probe Type:** Linear (dropdown)
- Pitch (μm):** 245
- Kerf (μm):** 30
- Height (mm):** 6.0
- Number of active elements:** 64
- Number of Lines:** 163
- Linear Scan:** Selected (radio button)
- Sectorial array:** Not selected (radio button)
- Radius (mm):** 50.0
- Phased array:** Not selected (radio button)
- Angle range ($^\circ$):** 30.0
- Transmitted Pulse:**
 - Transmit focus (x,y,z) (mm):** 0.0, 0.0, 70.0
 - Elevation focus (mm):** 23.0
 - Initial pressure (kPa):** 100.0
 - Apodization in transmission:** None (dropdown)
 - Apodization in reception:** None (dropdown)
 - Number of samples:** 256
- Signal to send:** Sine (dropdown)
- Central Frequency (MHz):** 3.0
- Number of cycles:** 3.0
- Phase ($^\circ$):** 0
- Transmission delay (s):** 0
- Sampling Frequency (MHz):** 50
- Window:** None (dropdown)

Fig.4. Probe settings

3.3 Medium definition

The second tab sets the medium dimensions, sampling, and properties.

The screenshot shows the 'Medium definition' tab with the following settings:

- Medium parameter:**
 - Medium density (kg/m³):** 1000.0
 - Speed of sound (m/s):** 1540.0
- Geometry:**
 - x axis maximum (mm):** 25
 - y axis maximum (mm):** 5
 - z axis minimum (mm):** 20
 - z axis maximum (mm):** 80
- Nonlinear parameter beta:**
 - Add inclusions:** Bubbles (dropdown)
 - Value:** 3.5
 - Add:** Button
- Attenuation:**
 - Attenuation $\alpha_{\text{ph}0}$ (dB/MHz/cm):** 0.500
 - Gamma:** 2.0
- Discretization:**
 - Number of points on x axis:** 128
 - Number of points on y axis:** 128
 - Number of points on z axis:** 200
- Scatterers:**
 - Number of scatterers per voxel:** 10
 - Distribution:** Diagonal (dropdown)
 - Save reflector data:** ☐

Fig.5. Medium definition

Attenuation

The relation between absorption and frequency can be set here.

Geometry

This defines the dimensions of the space where the scatters are placed and defined with the maximum lateral and elevation distances. In the z direction, the minimal and maximal depths to reach are defined. These depths are the ones used in the final image creation

Discretization

The discretisation in the x , y , and t axis is performed in the definition of the 3D matrix in the forward field simulation. The discretization of the z axis in the computation of the forward field is set in the Nonlinear Propagation tab, and the resulting field is interpolated on a new z axis which number of points is defined by “Number of points on the z axis”.

Nonlinear Parameter Beta

The default map is a constant medium with $\beta=3.5$. Then, by clicking on the add button, the user modifies the map using a new β value by adding regions or by importing a file. The dimensions of the imported image have no impact because interpolation is used in the field simulations. However, it has to be considered that the dimension of the map is set by the probe and space parameter. Indeed, the nonlinear map has dimensions in the lateral dimension $[-N_{\text{line}} \text{ Pitch} ; N_{\text{line}} \text{ Pitch}]$ and in the axial dimension $[0; z_{\text{max}}]$. The number of points, that composes this image, has no impact once loaded in Creanuis.

Scatters

The scatters’ density, N , allows to quickly select the number of scatters per resolution cell. However, in some cases, this number is directly the number of scatters in the medium. For example with the diagonal, vertical or PSF configuration, exactly N scatters are used in the medium. Moreover, with the grid scatters configuration, a grid of $N \times N$ is designed to simulate the medium. The backscattering amplitude follows a normal distribution. The scatters distribution can also be imported from a file.

3.4 Nonlinear propagation

This tab sets the used simulator to compute the forward nonlinear field. Two simulators can be used, the GASM and the SVEA. With the GASM, only two harmonics are computed one after the other, whereas the SVEA computes all the harmonics at the same time. GPU acceleration can be used to speed up the computation if the computer has a powerful enough NVIDIA graphics card. By default, only the maximum intensity over time in each frequency band is saved if GASM is selected. If SVEA is selected, only the total maximum intensity over time is saved. Different saving can be configured. Depending on the used save configuration, the amount of used disk space can critically change:

- Save 2D+t save the (x, z, t) pressure field
- Save 3D save the (x, y, z) maximal pressure amplitude
- Save 3D+t save the (x, y, z, t) pressure field

Visualizing the forward pressure field before reconstructing the RF image is possible by clicking the “Compute forward field [Preview]” button.

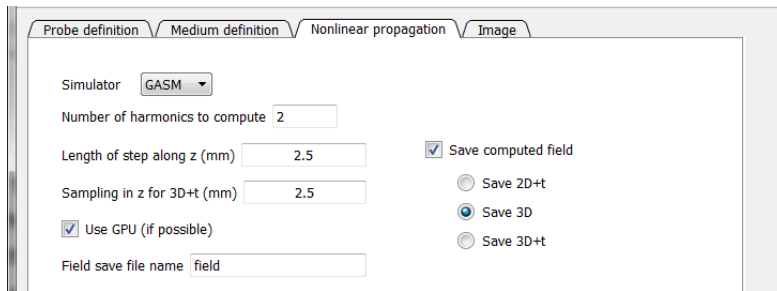


Fig.6. The Nonlinear Propagation tab

3.5 Image reconstruction

This tab has two displays to show the beamformed fundamental and second harmonic image, or the forward field if a field preview has been requested. Additionally, it can display saved nonlinear parameter maps, forward fields or RF images.

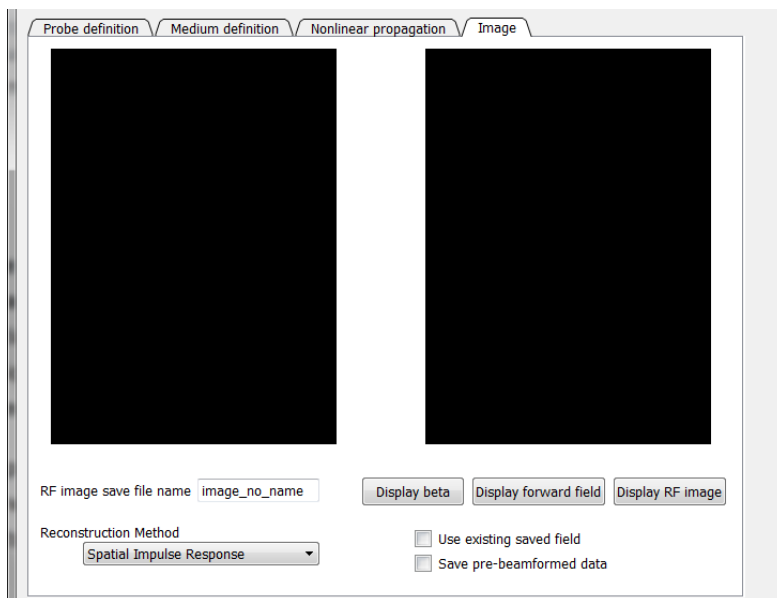


Fig.7. The Image tab

It contains the settings for image reconstruction. The image is saved under the specified name. Two reconstruction methods are available: “Delay and Sum” uses the full saved or pre-computed 3D+t field, whereas “Spatial Impulse Response” uses a 3D field with the maximum amplitude over time for each harmonic to scale up or down the same waveform for each voxel, and is thus suitable only for GASM-simulated forward fields.

By default, clicking the “Compute forward field and RF Image” conducts the nonlinear propagation to compute a forward field, but it can also use existing save fields by checking the corresponding box. It is possible to save the voltage trace of each transducer by checking the “Save prebeamformed data” box.

4 Data structure

4.1 Nlrf files

The nlrf file is the output format of the nonlinear RF image that is computed by Creanuis. The file is a binary file only written with floats numbers. A header of 18 floats is present. In the header different data are saved in the following order:

HEADER: Transmitted frequency, sampling frequency, speed of sound, initial pressure, density, pitch, kerf, height, number of elements, number of points on one RF line, third dimension of the RF image (different of 1 if the pre-beamformed data are saved), number of active elements, transmitted focus (z direction), elevation focus, minimal depth, maximal depth, number of transmitted cycles, transmitted phase (in degree).

Then, the other elements correspond to the amplitude of the RF image. The dimension of the radio frequency image is given by: the number of probe element, the number of points on one RF line and the number of active element if pre-beamformed image is saved.

4.2 Nonlinear coefficient files

The nonlinear coefficient file is a binary file that contains first, two entire N and M, and then NxM float elements. To create a nonlinear coefficient file, such configuration has to be used in order to be understood by CREANUIS.

4.3 Scatters files

The scatters file is a binary file that contains first, an entire N and then the position and the amplitude of each scatter (in float). The rest of the file is successively composed of the N positions x, the N positions y, the N positions z and the N amplitude values. To create a scatter file, such configuration has to be used in order to be understood by Creanuis.

5 Utilization of CREANUIS in command line

5.1 General overview

Creanuis can be used in command line in order to suppress the graphic interface and then, launch the simulation in a cluster for example. To do this, some arguments have to be added after the Creanuis is launched.

Obligatory arguments

- ◆ --path path_name: the user must specify the path where the save_settings.txt file is saved in order to access to the entire parameters need to configure CREANUIS. If the setting file is not placed in path_name directory, an error is return by CREANUIS.

- ◆ --scatters_scatters_file: the user must specify the file where the scatters position and amplitude are saved. Using CREANUIS in command line did not yet allow using the classical random, diagonal, grid... distribution. This file can be generated using the accompanying Matlab file.
- ◆ --image_name filename : the output simulated image is created with the name filename.nlr

Optional arguments

- ◆ --nonlinearity nonlinear_coefficient_file: if a specific nonlinear coefficient medium is desired, it has to be generated previously. If the --nonlinearity tag is not present, a nonlinear coefficient medium of $\beta=3.5$ is used in the GASM simulations.
- ◆ --debug debug_number: if the output messages are desired in the terminal, a number above 0 has to be selected. The number is the same as the graphic use of Creanuis. Let recall that the tag "Do nonlinear propagation" in the save_setting.txt has to be equal to 1 to do the GASM simulations.
- ◆ --signal_TX signal_file : if a specific signal to transmitted is required
- ◆ --sectorial R : if a sectorial array with a radius R need to be simulated
- ◆ --phased_array that : if a phased array probe with a range angle theta (in degree) need to be simulated

5.2 Save_setting file

Typical save_setting.txt file will contain the main parameter to load a previous simulated medium or launch a simulation in command line:

1 245.000003 :Pitch [microm]	23 512 :Discretisation in X dimension
2 29.999999 :Kerf [microm]	24 64 :Discretisation in Y dimension
3 6.000000 :Height [mm]	25 200 :Discretisation in Z dimension
4 0.000000 :Transmit focus x [mm]	26 256 :Discretisation in T dimension
5 0.000000 :Transmit focus y [mm]	27 2.500000 :dz discretisation in GASM[mm]
6 59.999999 :Transmit focus z [mm]	28 8.000000 :x maximum[mm]
7 23.000000 :Elevation focus [mm]	29 5.000000 :y maximum[mm]
8 1540.000000 :speed of sound [m/s]	30 0.000000 :z minimum[mm]
9 1000.000000 :density [m3]	31 100.000001 :z maximum[mm]
10 256 :Number of transmitted elements	32 1 :Do nonlinear propagation
11 256 :Number of lines	33 255 :Do one way field
12 3.500000 :fundamental frequency[MHz]	34 1 :Save all the field computed
13 100.000000 :Sampling frequency[MHz]	35 0 :Save prebeamformed image
14 5.000000 :Number of cycles	36 image_no_name :image filename
15 0.000000 :Delayed transmitted phase	37 field :field filename
16 0.000000 :Transmitted phase	38 E:/Work/CREANUIS/Soft/pressure_field/a_default :path of field files
17 None :Windows function transmitted	39 0 :Used nonlinear propagation tools (0:GASM, 1:SVEA)
18 100.000000 :Initial pressure [kPa]	40 0 :Scan type (0:Linear, 1:sectorial, 2:Phased array)
19 0.000000 :Attenuation reference [dB/cm/Mhz]	41 0 :Reconstruction method (0:spatial impulse response, 1:D&S)
20 2.000000 :Gamma coefficient	42 50.000001 :Sectorial radius [mm]
21 None :Apodization in transmission	43 30.000000 :Angle range for phased array scanning (degree)
22 None :Apodization in reception	

6 Accompanying Matlab files

6.1 General matlab function

With Creanuis, several accompanying files are proposed to be able to use the produced results in a Matlab interface. The files are divided in two categories and are summarized in Table 1:

- Files to read information saved by Creanuis
- Files to write information that can be read by Creanuis

Table 1. List of the accompanying Matlab files.

Read	Write
read_field.m	write_apodization.m
read_image_rf.m	write_image_rf.m
read_nonlinear_coefficient_file.m	write_nonlinear_coefficient_file.m
read_scatters_file.m	write_scatters_file.m
read_setting_file.m	write_settings.m
	write_signal_TX.m

The action of each file is detailed in the help header of the Matlab file. If specific apodization, scatters or nonlinear medium are required, it is recommended to use these files.

6.2 Given example

A second folder, matlab_example, contains some example to launch a simulation in command line, do the pre-beamforming image reconstruction, or to work on sectorial/phased array geometry. Comments are directly provided in such scripts.

7 Licence

The CREANUIS software has been placed under the CeCILL-B licence⁴. This licence gives to the user the authorization to use Creanuis and to publish works obtained using this software. The only condition is to cite in each work where Creanuis has been used the following publications:

- ◆ F. Varray, A. Ramalli, C. Cachard, P. Tortoli, and O. Basset, "Fundamental and second-harmonic ultrasound field computation of inhomogeneous nonlinear medium with a generalized angular spectrum method", *IEEE Transactions on Ultrasonics, Ferroelectrics and Frequency Control*, vol. 58, no. 7, pp. 1366-1376, 2011.
- ◆ F. Varray, C. Cachard, P. Tortoli, and O. Basset, "CREANUIS: A Nonlinear Radio Frequency Ultrasound Image Simulator", *Ultrasound in Medicine and Biology*, vol. 39, no. 10, pp. 1915-1924, 2013.

⁴ http://www.cecill.info/licences/Licence_CeCILL-B_V1-en.html

8 Bibliography

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