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HoloRec3D : A free Matlab[®] toolbox for digital holography

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Abstract

In-line digital holography is an imaging technique which is being increasingly used for studying 3D flows. It has been previously shown that very accurate reconstructions of objects could be achieved with the use of an inverse problems framework. The goal of HoloRec3D is to reconstruct the volume of interest using this approach. A simple Graphical User Interface accompanies the scripts to facilitate the use of this toolbox. A recently published multi-scale method is included providing the advanced users with a fast and accurate reconstruction.

1 Introduction

Digital Holography (DH) is a 3-D imaging technique which has been widely developed during the past few decades thanks to the enormous advances in digital imaging and computer technology. This technique achieves 3-D reconstruction of objects from a 2D hologram-image and reaches accuracies in the range of - or smaller than - the wavelength. As 3-D information coded in a digital hologram can be recorded in one shot, this technique can be used with high speed cameras to perform time-resolved 3-D reconstructions of high speed phenomena. This metrological tool is used in experimental mechanics, biology, or fluid dynamics.

Over the past decade, several algorithms for the analysis of holograms have been proposed. They are mostly based on a common approach to hologram processing: digital reconstruction based on the simulation of hologram

diffraction [1, 2]. These so-called classical approaches suffer from artifacts intrinsic to holography: twin-image contamination of the reconstructed images, image distortions for objects located close to the hologram borders. The analysis of the reconstructed planes is therefore limited by these defects [3]. In contrast to this approach, the inverse problems perspective does not transform the hologram but performs object detection and location by matching a model of the hologram [4, 5]. Information is thus extracted from the hologram in an optimal way [6, 7], leading to two essential results: an improvement of the axial accuracy [4] and the capability to extend the reconstructed field beyond the physical limit of the sensor size (out-of-field reconstruction [5]).

In this document, we introduce a Matlab[®] toolbox dedicated to Inverse Problems approach for digital hologram reconstruction. Accurate 3D reconstruction of in line digital holograms of spherical objects, typically droplets, bubbles [8] or beads is the direct target of HoloRec3D although the option of classical back propagation method is available for general objects. The theoretical background of the inverse problems approach can be found from the references.

HoloRec3D can be found here for download. The structure of this document is as following. In Sec. 2 the system requirements and configuration are described. In Sec. 3 the use of graphical user interface is detailed. We conclude this document by describing the use of sample scripts for a more advanced use of HoloRec3D in Sec. 4 which includes the use of multi-scale method [9].

Please kindly note that any use of HoloRec3D should be cited using this document as the reference:

M. Seifi, C. Fournier and L. Denis, "HoloRec3D : A free Matlab[®] toolbox for digital holography", HAL-UJM, Oct 2012.

2 Setting the environmental parameters

The system requirements for using HoloRec3D is the Matlab[®] environment equipped with the Image Processing and the Optimization toolbox. The code can be downloaded from here. All the folders should be unzipped in the folder "/HoloRec3D". This folder should be added to the Matlab[®]'s path. This can be done by opening the Matlab[®] environment, browsing to the folder "/HoloRec3D" and typing the following in the command line:

```
>> HoloRec3DPath(pwd);
```

This command adds the HoloRec3D's folder to the path. Another way is to add the folders manually to the path by opening the Matlab[®] environment and selecting "Set path..." from File in the toolbar. In the next window, the button "Add with subfolders" will add the selected folder ("/HoloRec3D") and its sub-folders to the path. This will change the path of the Matlab[®] permanently which is not recommended.

The mex functions are compiled for Matlab[®] R2009a and R2010b. If the version of Matlab[®] is different, this e-mail address can be used to receive the suitable ".mex" functions for a specific system configuration.

3 Getting Started : Graphical User Interface

The Graphical User Interface (GUI) provides a simple tool to use HoloRec3D without the need for a deep knowledge of the implementation. To start with the GUI, type the following in the command line:

```
>> GUI;
```

The window showed in Fig. 1 will be opened. This Window consists in three main parts: (i) Pre-process, (ii) Basics: Simulate and observe, (iii) Advanced: Process the hologram.

3.1 "Pre-process"

This part of the GUI is used to convert raw image files containing the captured holograms to the Matlab[®] data files (i.e., ".mat" files) and remove the background of the holograms. The background is calculated as the mean of the raw images. To use this option, the button "Browse" can be used in this section of GUI to browse to the folder containing the raw images, and to select one raw image. The processed data will be saved in the folder "/HoloRec3D/DATA" under the name "hologram_video_manual.mat". Using the button "Show the holograms" will show the video of the processed hologram in a separate figure.

3.2 "Basics: Simulate and/or visualize"

The second part of the GUI facilitates the simulation and the visualization of the (existing) holograms. It is possible to either simulate one hologram or

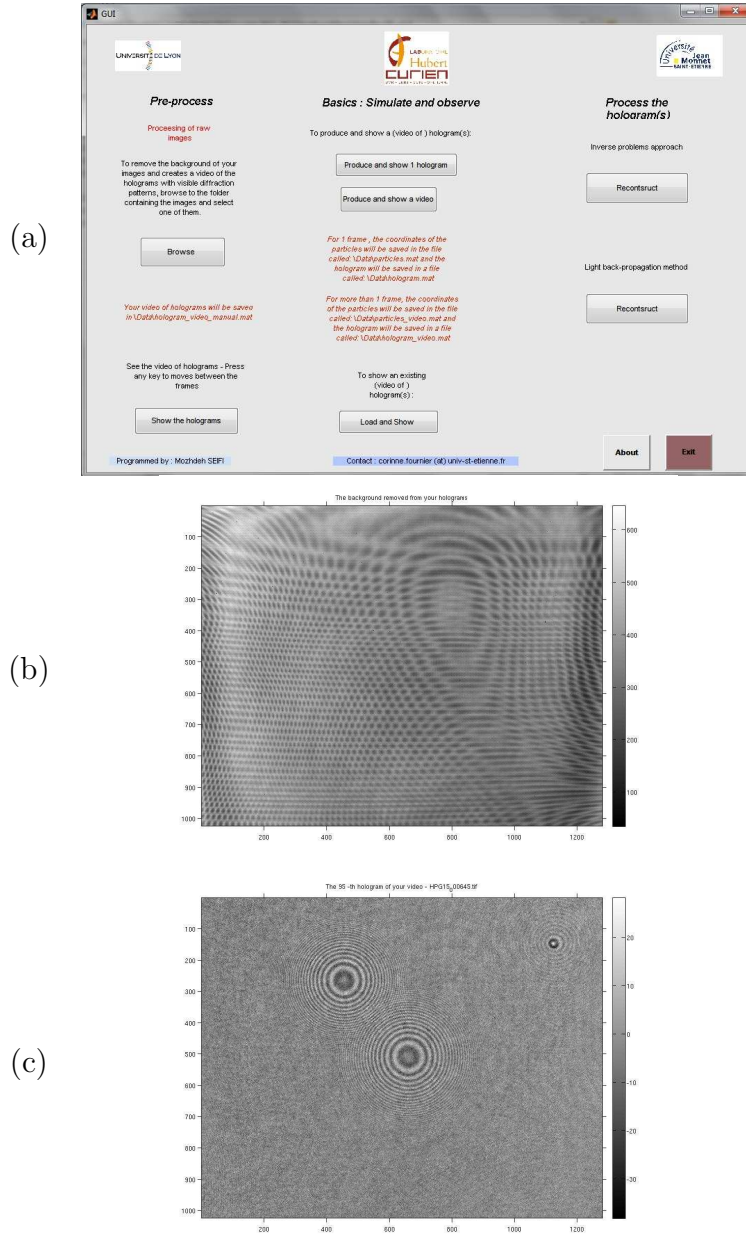


Figure 1: (a): The main window of the Graphical User Interface of HoloRec3D, (b): The calculated and removed background of raw images using the "Pre-process" part of the GUI. The raw holograms are the courtesy of the laboratory of Fluid Mechanics and Acoustics of Lyon (LMFA). (c) one hologram with removed background using the "Pre-process" part of the GUI.

a video of the holograms.

We provide an example which shows the work flow of the GUI until the simulation is finished. Selecting the button called "Produce and show a video" will guide the users to another window which asks for the number of frames in this video (the number of frames is equal to the third dimension of the matrices in Matlab[®]). After selecting the number of frames, the users are guided to provide the coordinates of the particles. Using this window, the users can choose between (i) manually providing the particles coordinates, (ii) randomly generating the coordinates, or (iii) loading an existing ".mat" file which contains the particle coordinates. The later choice requires a specific structure of the ".mat" file. The first Column of the matrix should contain the vertical coordinates of the particles in pixels, the second column should contain the horizontal coordinates in pixels, the third column should contain the depth (Z) coordinates in meters, and the forth column should contain the radii of the particles in meters.

We select the option "Manually". Fig. 2-a shows the window which shall be used to enter the coordinates. Any rows which contain zero, Inf, or NaN as the Z coordinate, won't be considered as a valid coordinate quartet. After entering the coordinates for each frame, user shall submit the values using the button "Submit the coordinates for the current frame". The number of particles can be different in different frames, but the user can't enter the coordinates for more than the number of frames he has entered in the previous window.

After entering the coordinates for all the frames, the users will be guided to another window (shown in Fig. 2-b) which asks for the application parameters, namely the laser's wavelength, the information about the sensor (i.e., pixel size, fill factor, dimensions in pixels), the range for the depth (Z) and the range for the radii, the field of interest (to have some particles placed out of field of view of the sensor), the laser intensity and the standard deviation of the white Gaussian noise. If the previously entered depth and radius information of some of the particles are not in the mentioned range, an error will appear on the screen and the user is asked either to manually enter the correct coordinates again, or to change the ranges for depth and radius.

After entering the correct setup information, the hologram(s) will be simulated and shown in a separate figure.

3.3 "Process the hologram(s)"

The last section of the GUI is used to reconstruct the volume of interest from the holograms. Two main approaches are implemented in this part: (i) inverse problems approach method , (ii) classical light back-propagation method. The inverse problems approach is implemented to process the holograms of spherical objects, whereas the light back propagation method can process the holograms of any types of objects. It should be noted that both implementation assume an inline setup for the hologram recording.

3.3.1 Inverse Problems Approach

The last part is dedicated to the hologram reconstruction using the inverse problems approach. Before starting the process, the users can see the coordinates of the particles stored in ".mat" files using the button "Display the information about particles". It is also possible to visualize the particles in 3D using the button "Visualize". The criteria maps which are used for the detection and rough estimation of the coordinates can be visualized using the button "Calculate". The users will be guided to another window which asks for the setup parameters, the depth and the radius of particles for the calculation of the criterion map,... On this window the users should select the ".mat" file containing the (video of) hologram(s) using the button "Load hologram(s) and calculate Qmap(s)". The calculated maps for the specified depth and radius are shown in a separate window (see Fig. 3-a).

To start processing the holograms using inverse problems approach, users should use the button "Start". After selecting the ".mat" file containing the holograms, users will be guided to a window asking for the setup parameters. Fig. 3-b shows the corresponding window.

Mask: using the toggle buttons, users can load a pre-defined mask to apply non-uniform weights on the pixels. The default Mask is a binary mask, containing 1 for the pixels on the sensor, and 0 for the pixels out of the field of view of sensor.

Noise: the standard deviation of the noise should be provided to proceed with the inverse problems method. If it is unknown, users can use the button in front of the corresponding field to crop a part of the hologram which contains only noise, and automatically calculate the standard deviation of noise. This step assumes the noise to be white and Gaussian .

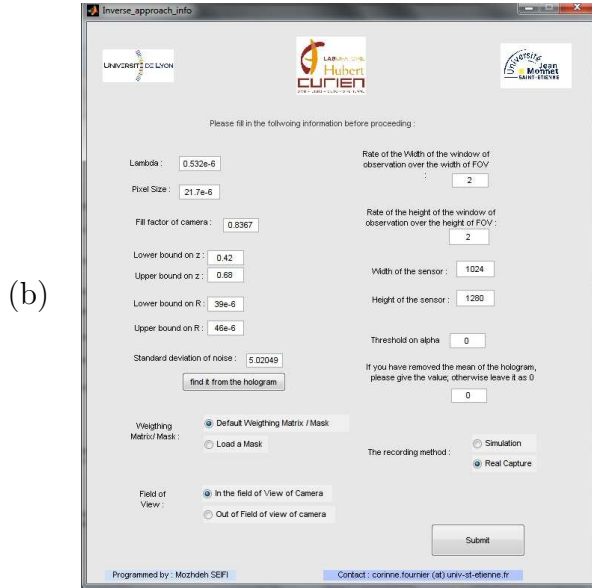
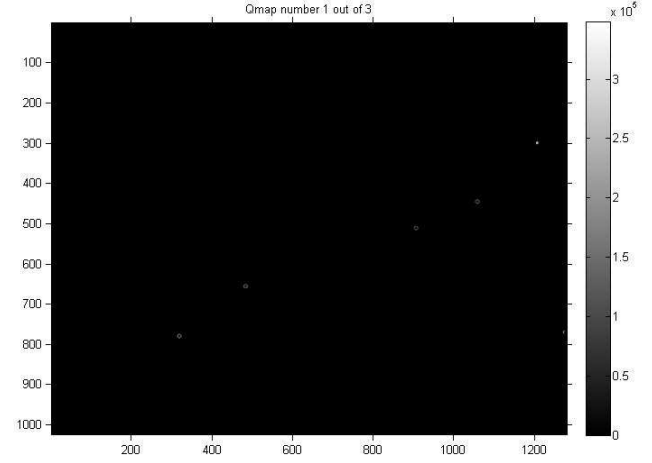
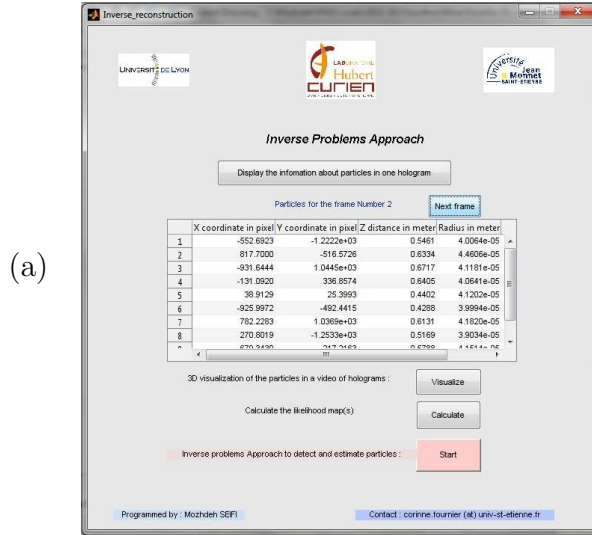


Figure 3: (a-1): The GUI for using the options of inverse problems approach, (a-2): Correlation map for $z=0.48$ m, $R=42 \mu\text{m}$. The holograms are the courtesy of the laboratory of Fluid Mechanics and Acoustics of Lyon (LMFA), (b-1): The GUI window which is used to define the application parameters for the hologram reconstruction using inverse problems approach.



Figure 4: The GUI for the light back propagation reconstruction method

3.3.2 Classical light back propagation method

To reconstruct a hologram using the light back propagation method, users can choose the corresponding button on the main GUI. In the next window, users are asked to set the application parameters like the sensor's pixel size, the laser's wavelength and the volume of reconstruction with the required sampling size in z . Two methods of reconstruction are implemented as the Fresnel reconstruction and the angular spectrum reconstruction. The option of zero-padding is added to remove the ghost images on the borders produced during the reconstruction of the truncated hologram. The reconstructed volume is visualized through two images which show the reconstructed Intensity and Phase for a specific depth value. A slide bar is placed under the images to facilitate the visualization of the volume changing depth values. (see Fig. 4)

4 Scripts for advanced usage

Although using the GUI of HoloRec3D is straightforward, several parameters are hidden from the users which decreases the flexibility of the implemented

methods. A more advanced use of the toolbox is to directly work with the functions and scripts. In this section, we introduce the contents of the folders and address two sample scripts which can be used to access the toolbox on a deeper level.

4.1 Folders and Files

HoloRec3D contains four main folders: (i) IPA, (ii) GUI, (iii) FAST, (iv) Data. "IPA" includes the ".m" source files, ".mex" binary files and the help for the ".mex" files. "GUI" contains the ".m" source files and the .fig files which together build the GUI of HoloRec3D. "FAST" includes additional ".m" files implementing a fast and accurate multi-scale framework. Finally "Data" contains the sample simulated/real holograms, coordinates of particles, and a "temp" folder used for internal parameter handling.

In addition to these folders, some simulated/real holograms are put on line which are accessible through this link. Users should unzip these folders before starting to use them.

4.2 Sample scripts

To start using HoloRec3D through the functions, users can find two sample scripts. The first one which introduces the use of inverse problems approach is placed in ". /HoloRec3D/IPA" under the name "MAIN_IPA.m" . The file contains the list of the function's parameters which are required to be set beforehand for (i) a simulation case, (ii) the case of the real holograms of LMFA, (iii) an unknown application which can be used by the users to apply their own application.

A second script introduces the multi-scale method. It is place in ". /HoloRec3D/FAST" under the name "MAIN_FAST.m" . Similar to the other script, this script is written to guide the users to use the multi-scale method.

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