European Community's Seventh Framework Programme

Grant agreement no. 216105

Real 3D – Digital holography for 3D and 4D real-world objects' capture, processing, and display

Deliverable 2.2 Report on digital hologram file format

Project information

Grant Agreement number	216105
Project acronym	Real 3D
Project title	Digital holography for 3D and 4D real-world objects' capture, processing, and display
Programme	Cooperation
Theme	Information and Communication Technologies
Call	FP7-ICT-2007-1
Funding scheme	Collaborative Project: small or medium-scale focused research action (STREP)
Project website	www.digitalholography.eu

Deliverable information

Deliverable no.	2.2
Deliverable name	Report on digital hologram file format
WP no.	WP2
Lead Beneficiary	CNR
Contributing Beneficiaries	UOULU, CNR, EPFL
Nature (R, P, D, O)	R <<as specified in Annex I, p.26>>
Dissemination level (PU, PP, RE, CO)	CO/PU <<as specified in Annex I, p.26>>
Due delivery date from Annex I	M11
Real 3D Board approval date	1/12/2008
Actual / Forecasted delivery date to the EC	3/3/2009

Table of Contents

1. Brief contents overview (Public)

A digital hologram file format for the Real 3D project is investigated. The requirements and the rationale for choosing HDF5 as the data format are explained. An introduction is given to the HDF5 format. The datasets, attributes, and interrelationships within a digital hologram file are suggested, and examples of how they would be structured in a HDF file are presented. Finally a numerical technique to multiplex and demultiplex digital holograms is proposed. This technique could be useful to perform an efficient storage and/or a efficient transmission, in terms of reduced amount of data, of digital holograms from the recording head to a remote display unit in separate locations.

2. Public sections (Public)

The public sections of this Deliverable are marked as such. All other sections are confidential. A draft of this Deliverable without the confidential sections will be posted on the Real 3D public website (http://www.digitalholography.eu).

3. Introduction (Public)

This Deliverable 2.2 consists of a report (due date Month 11) on the digital hologram file format for Real 3D and represents the activities within the Task 2.4. The activities included in this task have been started in Month 5 (June 2008) and the bulk of the activities were completed by Month 8 (September 2008). It is apparent that designing a file format is an ongoing task that will require continued (although intermittent and minor) support throughout the project.

Task 2.4 aims at the specification of a digital hologram file format. A file format able to capture all of the functionalities of digital holograms will be defined for still-holograms as well as for video holograms. The developed file format is expected to be used for all of the future applications in the field of digital holography with clear benefits. In fact, nowadays, each digital holography research group has its own special-purpose data format and set of processing routines, with different types of digital holograms (off-axis, phase-shifting, etc.) exhibiting various types of underlying data. The format associated with digital holograms would exploit the important feature of a digital hologram to have encoded a diffraction volume. Therefore, a single digital hologram could be used to generate many conventional videos with different features (scene focused at different focus planes, etc.). The format will be extensible in such a way as to facilitate the speckle reduction, compression, and file type conversion techniques developed later in the project.

Two hologram file formats are proposed for Real 3D. The first is a version for long term archiving of hologram data, for compatibility between Beneficiaries, compatibility with new technologies into the future, and highly extensible by individual Beneficiaries. This is the format outlined in this Deliverable.

After significant investigations, it is proposed to implement the file format in such a way as to make it compatible with the HDF (Hierarchical Data Format) standard (http://www.hdfgroup.org/) of the National Center for Supercomputing Applications (NCSA) University of Illinois at Urbana-Champaign. Specifically, HDF5 format is chosen. This format will allow all of the requirements of the Consortium to be met, promises to be a format with long-term stability, and is compatible with software used by members of the Consortium – HDF5 has interfaces for Java, C, Mathematica, MATLAB, and GNU Octave (a free software largely compatible with MATLAB).

The second file format will be designed specifically for the model of primary display outlined in the Real 3D Description of Work. Work on the second file format has not yet begun. It will begin when more details of the model of primary display are finalised, as the work on hologram video compression develops, as the requirements for live "hologram streaming" experiments are decided, and as the network issues between capture and display are better understood. It will be a restricted version of the other file format. It will be designed to be as streamlined as possible to facilitate the transmission chain from capture to display, and any live "hologram streaming" experiments. If required, it will contain features that will be specific to the model of primary display, and so its lifetime may only be for the Real 3D project. It will be used for testing and experimentation, and the knowledge gained from its use will be fed back into the archive data format as appropriate.

It is planned to make the two file formats compatible during the life of the project so that one can convert between the two of them automatically.

8. Proposed technique to numerically multiplex and demultiplex digital holograms (Public)

In this section we propose a technique to multiplexing and de-multiplexing numerically digital holograms with the aim to optimize their storage and/or transmission process. Usually, the spatial multiplexing of digital holograms is obtained optically recording simultaneously more than one fringe pattern on the same CCD. Depending on the different experiments, one or more reference beams with different angles are used to obtain interference fringe patterns with different spatial frequencies and oriented along different directions. All the holograms are superimposed in one composite CCD frame, and each of them can be independently reconstructed through a digital spatial filtering if the image bandwidth of each hologram is sufficiently low.

De-multiplexing is obtained as follows. Each individual hologram is filtered out by performing the digital Fourier transform of the multiplexed hologram. The filtering in Fourier spectral domain is done by selecting a pass-band corresponding to the desired hologram. Then the inverse Fourier transform on the filtered result is computing with aim of obtaining a separate digital hologram for each of the multiplexed signals. Obviously, the size of the object spectrum in the Fourier plane determines how many digital holograms can be efficiently multiplexed. In this way, up to three digital holograms have been multiplexed without decreasing the spatial resolution, that is using all the aperture of the CCD array.

The space-bandwidth product (SBP) of a hologram in digital holographic microscopy is inversely proportional to the focal length of the objective lens and is proportional to the object magnification. Therefore, if we use lenses with short focal length to obtain a large magnification, as usually occurs in microscope configuration, the hologram SBP is such that not more than two holograms can be separated in the Fourier plane and, therefore, only two holograms can be optically multiplexed.

To overcome this problem, we propose a novel approach to numerically multiplex/demultiplex digital holograms recorded in the microscopic configuration. Exploiting the unique capability of DH to manage numerically the complex wavefronts, we reconstruct the object wave field at an intermediate plane, that is, essentially the back focal plane of the imaging lens.

In this plane the object wavefield is proportional to the Fourier transform of the complex amplitude of the wave at an input plane.Therefore, we obtain only the spectrum of the object wave field, removing the contribution of the carrier frequencies (that is the chirped phase factor coming from the interference between the plane reference beam and the curvature of the object beam introduced by the microscope objective).

Then, we choose a mask to filter each hologram in the LFP. The red frame in Fig.15 indicates the shape and the dimension of the used filtering window, that is 50 X 50 pixels around the carrier frequency of the object spectrum, whose position depends on some geometrical parameters of the experimental setup such as the angle between the reference and the object beams and on the reconstruction distance d. The transmittance of the mask is 1 within the frame and 0 outside. Obviously, reducing the dimension of the filtering window will increase the number of holograms we can encode in one single hologram.

On the other hand, the size of the filtering window should be larger than the object bandwidth in order to retain the spectral information. Then, the complex-value arrays are stitched in order to encode up to one hundred digital holograms in a single computer generated hologram (see Fig.15).

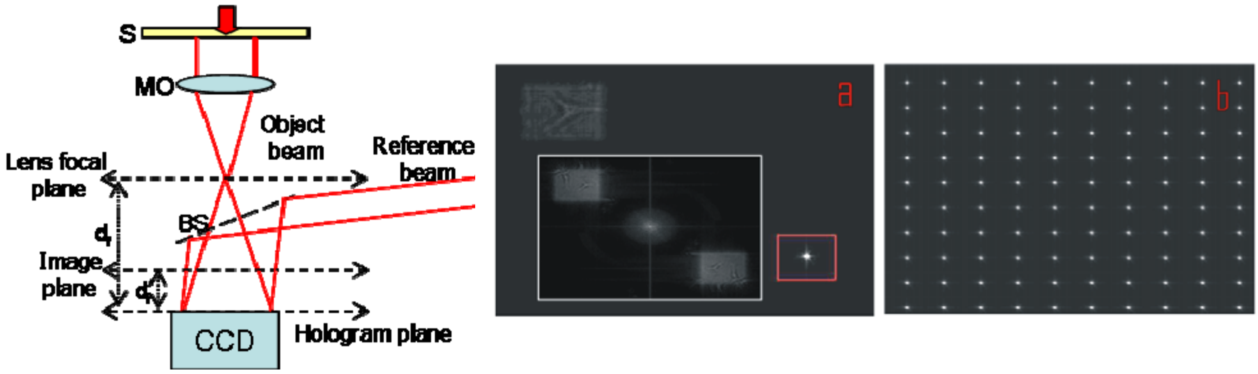

Fig. 15. (left) DH setup; (right) (a) Amplitude reconstruction of one hologram in the lens focal plane (LFP). The red frame indicates the used filtering window, 50 X 50 square pixels around the carrier frequency of the object spectrum. The inset shows the amplitude of the hologram Fourier transform. (b) Amplitude of the synthetic spectrum obtained by the numerical multiplexing in the LFP of 100 digital holograms.

The used technique can be thought of as a two-dimensional frequency-division multiplexing (FDM). FDM technique is a widely used form of signal multiplexing where multiple baseband signals are modulated on different frequency carrier waves and added together to create a composite signal. Our method can be considered the spatial analogous of the FDM technique. In fact, a spectral shift, that is a spatial carrier frequency, is applied to each object spectrum. Then, all the spectra are added together to create a composite complex hologram.

The proposed approach allows correct multiplexing and de-multiplexing of up to one hundred digital holograms. This technique could be useful to perform an efficient storage and/or a efficient transmission, in terms of reduced amount of data, of digital holograms from the recording head to a remote display unit in separate locations.

This complex-value array contains the information about the phase and amplitude of all one hundred holograms. It has to be transmitted with the multiplexing key. In fact, the numerical de-multiplexing needs the precise knowledge of the frequencies of the spatial carrier waves of all the holograms. Therefore, the receiver can de-multiplexed the synthetic spectrum and reconstruct all one hundred holograms only knowing the multiplexing key that have to be send together with the synthetic spectrum.

In the de-multiplexing process, the hologram composed in the LFP is filtered selecting one by one the single holograms that, then, are numerically reconstructed in the image plane. Then, we can compare the reconstructions obtained by the proposed FDM technique to those one coming from the original holograms.

In Fig. 3a and Fig. 3b are shown the phase reconstructions of one hologram as acquired by the CCD (left) and after the multiplexing/de-multiplexing process (right). Comparing the two kind of reconstructions, the distortion caused by the filtering process is not evident. In Fig.3c we have plotted the difference between the two phase reconstructions in order to evaluate the distortion.

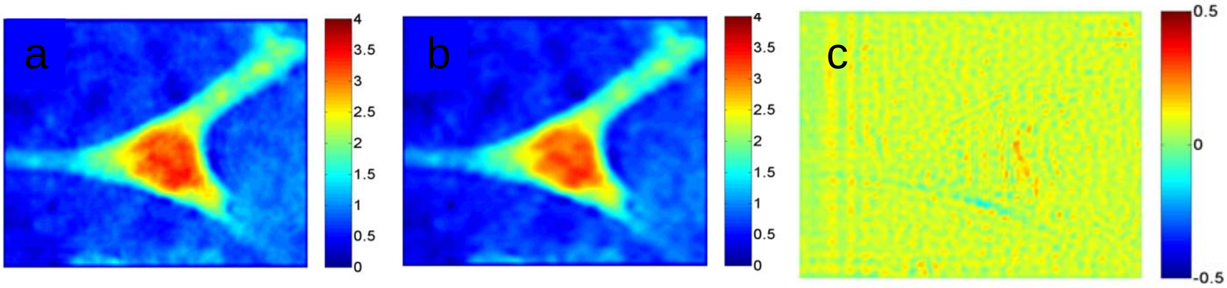

Fig. 16 Phase reconstructions of one hologram as acquired by the CCD (a) and after the multiplexing/de-multiplexing process (b); (c) 2D distribution of the difference between the two phase reconstructions in (a) and (b).

The mean value of the two-dimensional distribution of this phase difference is 0.068 rad with a variance of $1 * 10^{-3}$ rad, while the maximum value is 0.23 rad. Looking at Fig. 3c, it is clear that the maximum phase difference is situated on the cell border. This result is caused by the use of the filtering window that acts as a band-pass filter with limited bandwidth, cutting the high spatial frequencies due to the edges.