2010 12th International Workshop on Cellular Nanoscale
Networks and their Applications (CNNA)

GPU implementation of Volume Reconstruction and Object detection in Digital Holographic Microscopy.

László Orzó, Zoltán Göröcs, István Szatmári, and Szabolcs Tőkés
Cellular Sensory and Wave Computing Laboratory
MTA SZTAKI
Budapest, Hungary
Email: orzo@sztaki.hu

***Abstract*—Using Digital Holographic Microscopy (DHM) we can gather information from a whole volume and thus we can avoid the small depth of field constraint of the conventional microscopes. This way a volume inspection system can be constructed, which is capable to find, segment, collect, and later classify those objects that flow through an inspection chamber. Digital hologram reconstruction and processing, however, require considerable computational resources. We are developing volume reconstruction and object detection algorithms that can speed up considerably by parallel hardware implementation. Therefore, we put these tasks into operation on a GPU. As data transfer of the reconstructed planes would slow down the algorithm, all the reconstruction, object detection processes are to be completed on the parallel hardware, while fine tuning of object reconstruction and classification will be done on a CPU later. The actual speed up of the GPU implemented algorithm comparing to its conventional CPU realization depends on the applied hardware devices. So far we reached a 10 times acceleration value.**

***Index Terms*—Digital Holographic Microscopy, GPU, Volume reconstruction, Object detection, Volume inspection**

I. Introduction

The complex wavefront of the coherently illuminated volume can be recorded in a single hologram [1]. This way the DHM can overcomes the trade off between magnification and resolvable depth of focus of conventional microscopes. A special digital algorithm can be used to reconstruct the magnified images of the objects at different depths [2]. Tracking of the moving microorganisms in a volume is not feasible using conventional microscopy, due to the small depth of focus constraint, but can be done efficiently using the DHM [3]. We can record a sequence of holograms and find the object positions within the reconstructed volumes. The DHM seems to be an optimal architecture for volume inspection.

We apply an in-line holographic architecture as this arrangement provides the largest achievable field of view and so the highest resolution. Furthermore, this architecture can be implemented in a simple way: just changing incoherent illumination of the conventional microscopes to an appropriate coherent light source (see Fig. (1)). We apply fiber coupled diode lasers, which provide a nearly ideal reference wavefront. The in-line holographic architecture, however, causes some special noises at the reconstruction: twin image and zero order noises are the most prominent ones. These can be eliminated or considerably decreased by the use of special algorithms, which usually requires the determination of the objects proper supports and reconstruction distances [4].

Support, here, means that area, which cover all the pixels of the chosen reconstructed object.

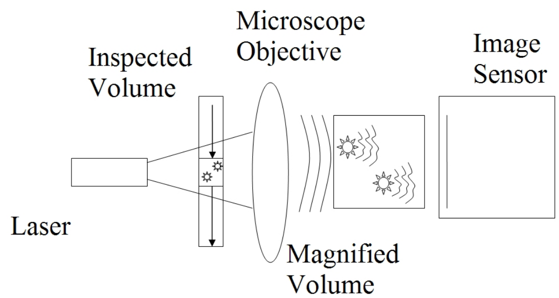

Fig. 1. In an in-line digital holographic microscope the measured hologram is produced by the interference of the reference beam, - which serves for the illumination also - and the objects' diffracted wavefronts.

Digital hologram reconstruction is based on simulating the light propagation of the hologram's complex wavefront. Here, we apply the angular spectrum method that is the digital implementation of the Fresnel-Kirchhoff diffraction integrals [5].

$$H(d) = \mathcal{F}^{-1}\{\mathcal{F}\{H\}e^{ik_z d}\}, \tag{1}$$

where

$$k_z = \frac{2\pi}{\lambda}\sqrt{1-(\lambda f_x)^2-(\lambda f_y)^2}, \tag{2}$$

This method does not assume any approximation, not like the frequently used Fresnel diffraction formulas [6], where paraxial approximation has to be satisfied. Angular spectrum method is based on the convolution of the hologram with a propagation distance dependent kernel (an appropriate spherical wavefront) that can be implemented by 2D fast Fourier transform routines (see Eq. (1)).

The DHM is capable to scan a volume of several cubic millimeters with approximately 0.5μm lateral resolution. Our goal is to reconstruct and track the appearing objects in the observed volume. Later we intend to use these reconstruction data for classification.

Reconstruction of the whole volume and finding the objects, even if they occur sparsely, require considerable computational

978-1-4244-6678-8/10/$26.00 ©2010 IEEE

resources. Any conventional CPU implementation appears to be too slow for any viable volume inspection application. As the application of parallel hardware can considerably enhance the speed of the volume reconstruction and object detection algorithms, we intend to implement them on GPU.
Other parallel implementation architectures was also considered, e.g., FPGA and Cell based devices, as they can provide comparable or even higher computing power [7]. Nevertheless, from price/performance, interfacing, and programming time point of view [8] , the application of a GPU device seems to be an optimal choice. In this paper, in section II we outline the developed volume reconstruction and object detection algorithms, then we review the details and limitations of the present GPU implementation, and finally in section III we present the results and discuss the aimed further implementation issues.

II. ALGORITHM

The first step of the algorithm is to determine an approximate reconstruction distance for the objects appearing within the inspected volume. This is fulfilled by the layer by layer reconstruction of the measured hologram, and finding the extreme values of an applied proper focus measure within this reconstructed volume [9]. The thickness of the reconstructed layers is defined by the depth of field of the optical system. It can be 5-10μm depending on the applied magnification value. This way the reconstruction of 25-100 layers is required for the whole volume, as each layer might contain some of the appearing objects. In the case of 1000x1000 pixel images, the computation can take several seconds on a conventional computer. We show a measured hologram in Fig. (2).

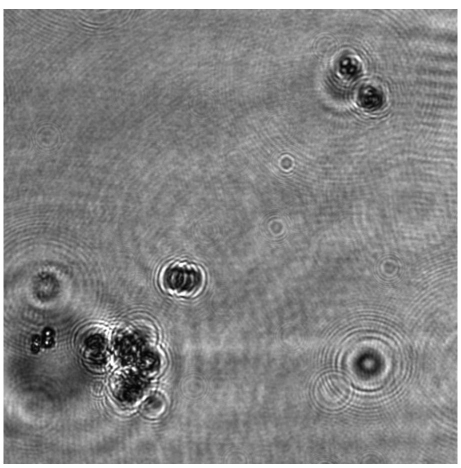

Fig. 2. The measured hologram.

We determine the focal distance for each object algorithmically. In each reconstructed layer we measure the local averaged contrast. This is a more or less proper focus measure (detailed later) and its global maximum defines the object estimated position within the volume. Evaluation of this focus measure can be solved by simple CNN template operations, therefore their GPU implementation seems straightforward [8].

In Fig. (3), we show the global maxima of the measured local averaged contrast. White peaks show the position of the objects with high local contrast values. In Fig. (4), the corresponding reconstruction distances are mapped.

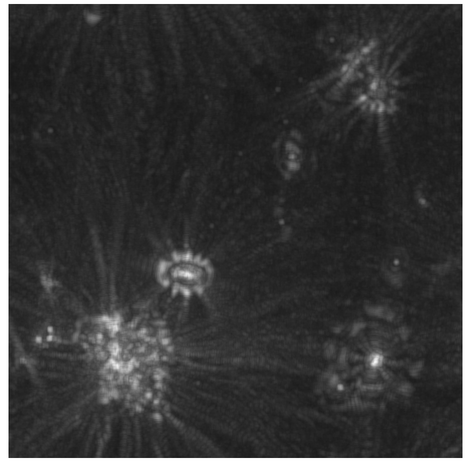

Fig. 3. Local averaged contrast maxima in the reconstructed volume.

Fig. 4. The map of then reconstruction distances corresponding to the measured contrast maxima (see Fig. (3).

It is worth mentioning that phase and amplitude, and mixed (phase and amplitude) objects have different local contrast extreme, this way the measured maxima only approximately defines the object correct reconstruction distances. However, using these data we can find the position of the high contrast objects and their approximated reconstruction distance and the corresponding object support can also be determined. These approximated reconstruction distances and support data seem adequate to decrease the twin image and zero order noises of the holographic reconstruction, and to eliminate the object's diffraction on the other nearby objects' reconstructions.

We have developed a DHM volume segmentation algorithm, which can segment the measured hologram into the sub-holograms of the individual objects. The algorithm uses a

couple of simulated wavefront propagation steps, therefore, it seems logical to implement also on a GPU. In Fig. (5), we show the magnified part of the original hologram (see Fig. (2)), the segmented object's sub-hologram and the remaining hologram. It can be seen that the diffraction pattern of the segmented object is totally removed from the original hologram, while diffraction fringes of the other objects was not erased. As the highest contrast objects are segmented first, their diffraction pattern is totally removed from holograms of the not yet segmented objects.
As this method produces a noise free segmented in-line hologram, it becomes possible to apply conventional twin image elimination routines [10] , that can determine the complex amplitude distribution of the reconstructed object.

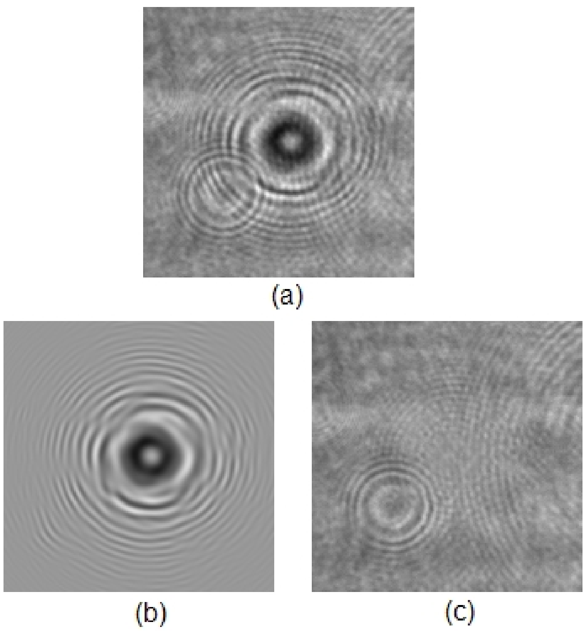

Fig. 5. Magnified part of the measured hologram (a) - is segmented to two subholograms according to the object's hologram (b) and the remaining hologram (c). All the diffraction patterns of the object are extracted during the segmentation, while the diffraction patterns of other objects are still recognizable on the remaining hologram.

The reconstructed objects complex amplitude data can be used later for the rendering of the object 3D structure by some more elaborated volume reconstruction algorithm. Furthermore, the objects exact position within the volume was also determined [11].

It was shown earlier that DHM reconstruction can be accelerated considerably using a GPU [12].
Unfortunately, these earlier approaches did not aim to reconstruct a whole volume, but only a single layer. Consequently, this method is not applicable in a volume inspection application. Furthermore, if we implement the algorithm on a GPU not only the volume reconstruction, but object detection, segmentation and processing tasks as well, we can considerably increase the speed of the processing by avoiding the otherwise necessary large data transfer and memory load requirements. Focus measurement tasks can be easily implemented on a GPU as they are using simple convolutions with separable kernels as we mentioned earlier. The hologram segmentation and twin image removal algorithms are based on the application of wavefront propagation steps and this way their GPU implementation is viable.

III. RESULTS

So far we were able to implement the volume reconstruction steps on GPU. The algorithm implementation uses the CUDA-FFT library and parallelized point-wise array multiplication routines. The implementation of this step require the most processing in the whole algorithm, and can be applied not only in the reconstruction but in the segmentation and twin image removal steps also. The acceleration of the algorithm depends on the applied GPU and CPU hardware, but we reached 10 times speed increase. We used a GeForce 8800 GTX GPU card, with an AMD Athlon 64 X2 5600+ CPU with 2GB RAM. The implementation of object detection and the other processing steps will considerably increase this gain as reduces the required data transfers.

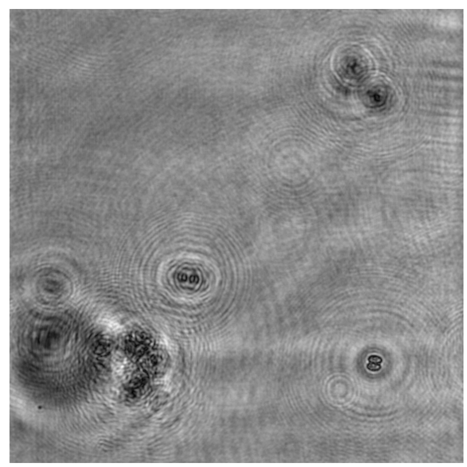

Fig. 6. The CPU simulation of the hologram reconstruction at an object focal plane. The absolute value of the reconstructed wavefront is displayed.

The application of single precision operations seems adequate for DHM volume reconstruction as does not lead to any observable image degradation ($RMSE \approx 10^{-4}$). However, the implementation of the convolution kernel calculation (see Eq. (2)) on the GPU leads to erroneous results (against the claims of [12]), therefore it has to be computed on CPU (causing small overall data transfer overhead) or be implemented on GPU by applying double precision processing, if it is available.

IV. CONCLUSION

We were able to implement volume reconstruction algorithm on a GPU and achieved up to 10 times acceleration using a GeForce 8800 GTX card. Furthermore, acceleration

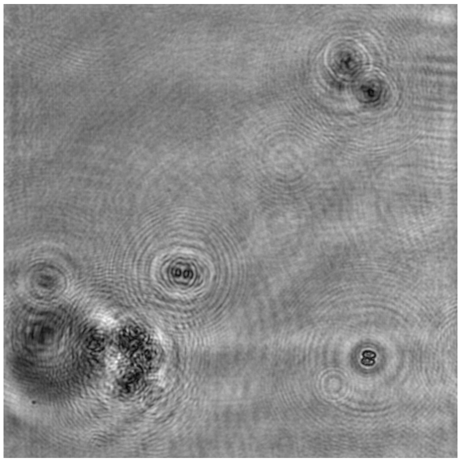

Fig. 7. The GPU based simulation of the hologram reconstruction (compare to Fig. (6).

will be achieved if the whole algorithm (object detection, segmentation, twin image removal) will be implemented on GPU and if the convolution kernel will be computed off line. The DHM volume inspection system can efficiently apply the parallel GPU architecture. In the case of decreased resolution holograms by GPU implementation real time tracking of the objects is achievable. This can be used in a combined volume inspection system that unites the advantages of holographic and conventional microscopes.

REFERENCES

[1] M. M. I. K. H. Xu, WB Jericho, "Digital in-line holography for biological applications," *PNAS*, vol. 98, no. 20, pp. 11 301–11 305, 2001.

[2] J. Garcia-Sucerquia, W. Xu, S. Jericho, P. Klages, M. Jericho, and H. Kreuzer, "Digital in-line holographic microscopy," *Applied optics*, vol. 45, no. 5, pp. 836–850, 2006.

[3] J. Garcia-Sucerquia, W. Xu, S. Jericho, M. Jericho, and H. Kreuzer, "4-d imaging of fluid flow with digital in-line holographic microscopy," *Optik-International Journal for Light and Electron Optics*, vol. 119, no. 9, pp. 419–423, 2008.

[4] L. Denis, C. Fournier, T. Fournel, and C. Ducottet, "Numerical suppression of the twin image in in-line holography of a volume of micro-objects," *Measurement Science and Technology*, vol. 19, no. 7, p. 074004 (10pp), 2008. [Online]. Available: http://stacks.iop.org/0957-0233/19/074004

[5] J. Goodman, *Introduction to Fourier optics*. Roberts & Company Publishers, 2005.

[6] T. Colomb, J. Kühn, F. Charriere, C. Depeursinge, P. Marquet, and N. Aspert, "Total aberrations compensation in digital holographic microscopy with a reference conjugated hologram," *Appl. Opt*, vol. 42, pp. 1938–1946, 2003.

[7] Z. Nagy, *Implementation of emulated digital CNN-UM architecture on programale logic devices and its applications*. Department of Image Processing and Neurocomputing, University of Pannonia, Veszprém, Hungary, 2007.

[8] B. Soos, A. Rak, J. Veres, and G. Cserey, "Gpu boosted cnn simulator library for graphical flow-based programmability," *EURASIP Journal on Advances in Signal Processing*, 2009.

[9] M. Tachiki, M. Itoh, and T. Yatagai, "Simultaneous depth determination of multiple objects by focus analysis in digital holography," *Applied optics*, vol. 47, no. 19, pp. D144–D153, 2008.

[10] G. Koren, F. Polack, and D. Joyeux, "Iterative algorithms for twin-image elimination in in-line holography using finite-support constraints," *Journal of the Optical Society of America A*, vol. 10, no. 3, pp. 423–433, 1993.

[11] F. Palacios, J. Ricardo, D. Palacios, E. Gonçalves, J. Valin, and R. De Souza, "3d image reconstruction of transparent microscopic objects using digital holography," *Optics communications*, vol. 248, no. 1-3, pp. 41–50, 2005.

[12] T. Shimobaba, Y. Sato, J. Miura, M. Takenouchi, and T. Ito, "Real-time digital holographic microscopy using the graphic processing unit," *Optics Express*, vol. 16, no. 16, pp. 11 776–11 781, 2008.