Lyncée tec DHM

GPU-accelerated dual-wavelength digital holography

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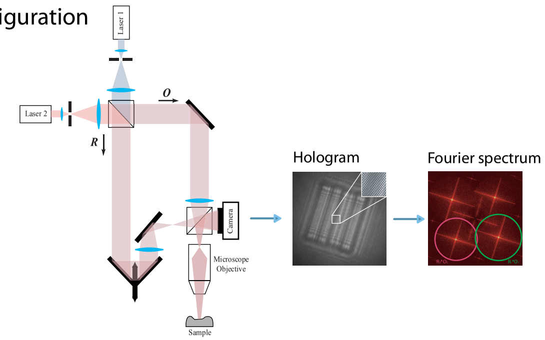
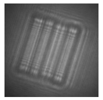
Dual-wavelength digital holography

Experimental configuration

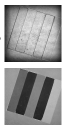


Numerical reconstruction (single wavelength)



Pre-processing → Fresnel propagation
(windowing, frequency selection)

Amplitude
Phase



→ Post-processing
(optical aberration compensation, unwrapping...)

- Phase → Sample height $z = \frac{\varphi\lambda}{2\pi}$

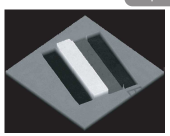
$\varphi \in [-\pi;\pi] \Longrightarrow z \in [-\frac{\lambda}{2};\frac{\lambda}{2}]$ Nanometric resolution !

- Fresnel propagation
  - compute complex wavefront ψ at distance d
  - approximated by $\psi(\xi,\eta) = FFT^{-1}\left[FFT\left(I_H(k,l)\right)e^{i\pi\lambda d\left(\frac{k^2}{(N\Delta x)^2}+\frac{l^2}{(N\Delta y)^2}\right)}\right]$

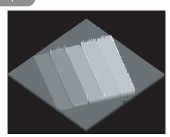
Dual wavelength reconstruction

- Sythetic wavelength $\varphi_2 - \varphi_1 = \frac{2\pi z}{\lambda_2} - \frac{2\pi z}{\lambda_1} = \frac{2\pi z}{\Lambda}, \Lambda = \frac{\lambda_1\lambda_2}{\lambda_1 - \lambda 2}$
- $\Lambda \gg \lambda_1, \lambda_2$ → Extended measurement range (several microns, instead of nm)

1.2 µm high Si staircase sample



Phase map @ λ_1 = 760 nm



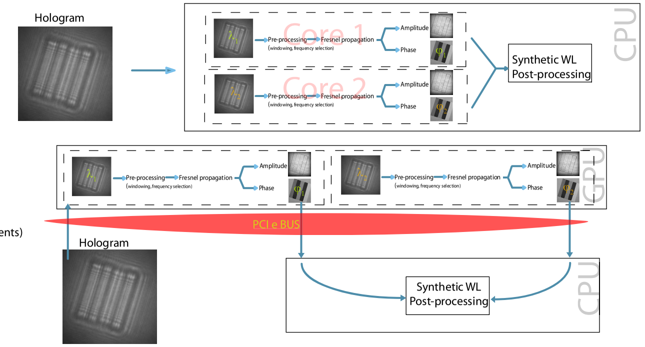
Topographic map @ Λ = 6.4 µm

- One propagation needed for each wavelength !

Results

Implementation

- CPU implementation
  - single precision floating-point computations
  - Intel IPP libraries
  - Intel TBB libraries (multicore CPU), run reconstructions in parallel
- GPU implementation
  - using NVIDIA's CUDA libraries
  - PCIe memory bandwith bottleneck
    perform pre-processing + Fresnel propagation on GPU
  - Limitations
    sequential processing (simpler, reduced GPU memory requirements)

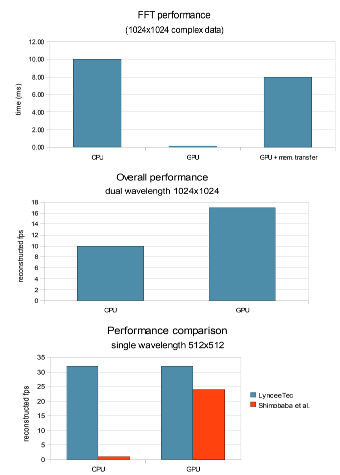


Hardware configuration

- Consumer-grade workstation (Dell Optiplex 960)
  - Intel Dual core CPU @ 3.16GHz
  - NVidia GeForce 9800GT graphic card
- Baumer CCD camera (up to 20 fps for 1024x1024 images)

Performance

- Fast Fourier Transform (1024x1024 complex array)
  - CPU (IPP) : ~ 10ms
  - GPU (IPP) : less than 200 µs ! ... + memory transfer (round trip): ~ 8ms !!
- Overall (1024x1024 holograms)
  - CPU (IPP) : 10 reconstructed frames per sec.
  - GPU : 17 reconstructed frames per sec. !
- Comparison
  - "Real-time digital holographic microscopy using the graphics processing unit"
    Shimobaba et al., Opt. Express 2008
  - Single wavelength holography
  - CPU implementation: 1 reconstructed frame per second... for 512x512 holograms
  - GPU implementation: 24 reconstructed frames per second
  - Our implementation: 32 fps achieved for 512x512 holograms using GPU or CPU (limitation of the camera)...



Conclusions and future works

- 70% of performance gain using GPU
- Perform post-processing on GPU (eg. phase unwrapping)
- Process each wavelength asynchronously (multi-GPU ?)

This research is funded from the European Community's Seventh Framework Programme FP7/2007-2013 under grant agreement 216105