United Nations Educational, Scientific and Cultural Organization

International Year of Light 2015

The National Centre for Research and Development

Pico-projection based on real-time computer holography

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Why projection?

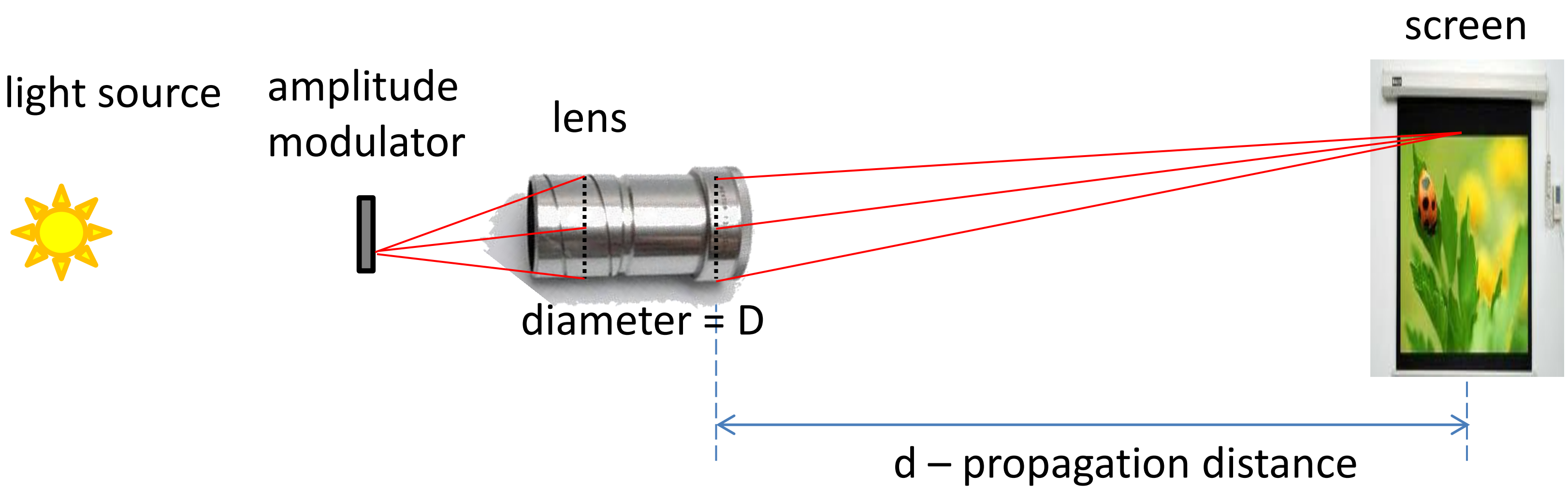
- Big screen from a small device

- Miniaturized pico-projectors for handhelds

Problem to be solved

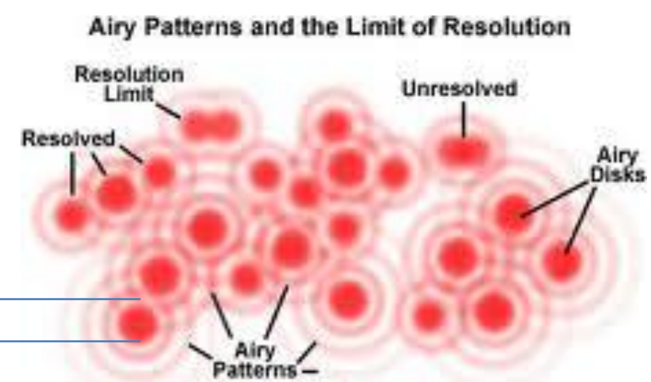
”To create a high-quality color light distribution at the projection plane with a miniaturized and efficient device.”

Classic projection

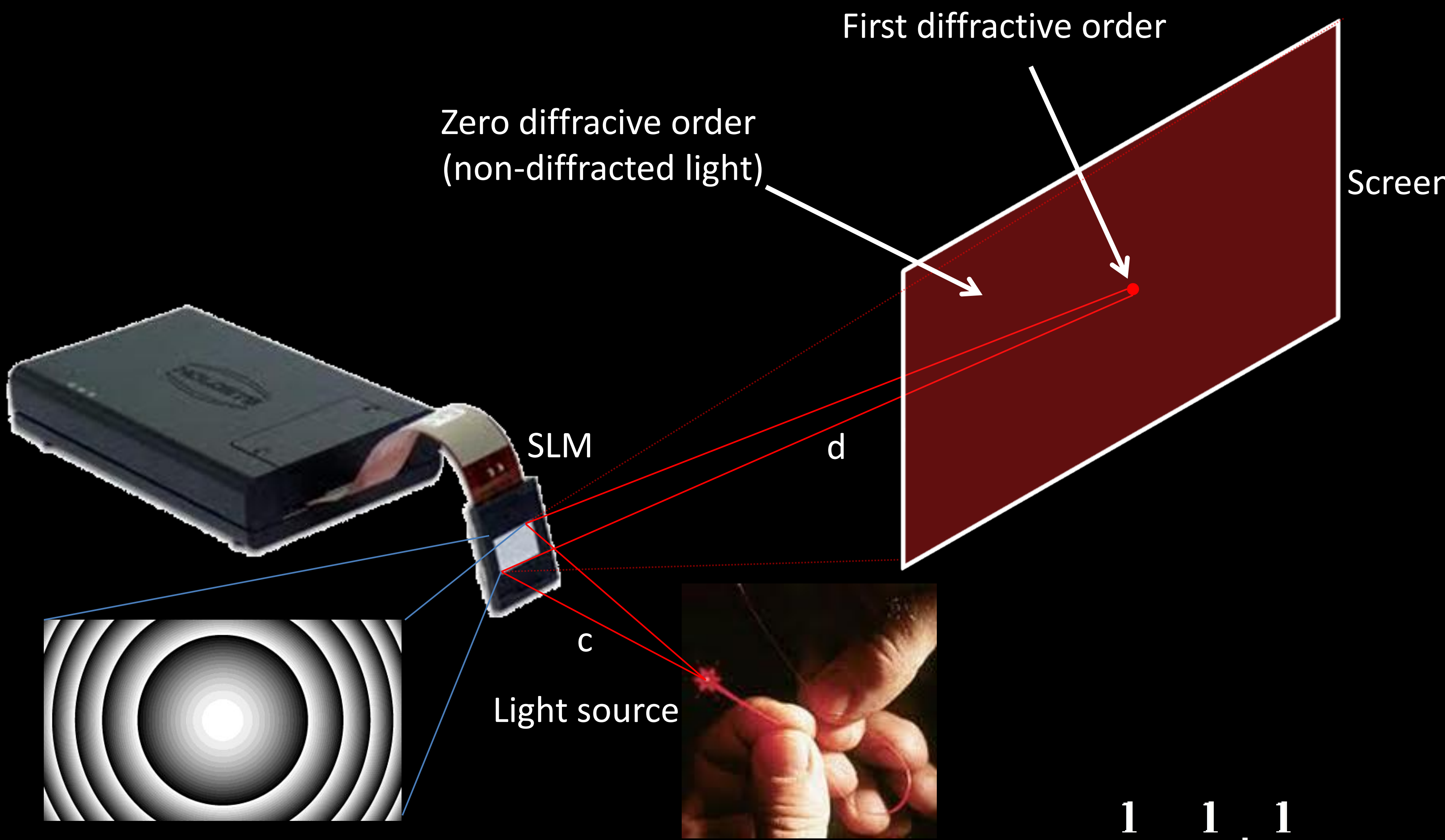


- Selective light absorption (light losses)
- 1-to-1 imaging of modulator pixel into screen pixel
- Complicated, large and expensive lens to minimize aberrations
- Problem of the diffraction on the lens aperture:

$$2r = \frac{1,22\lambda d}{D} \rightarrow r$$



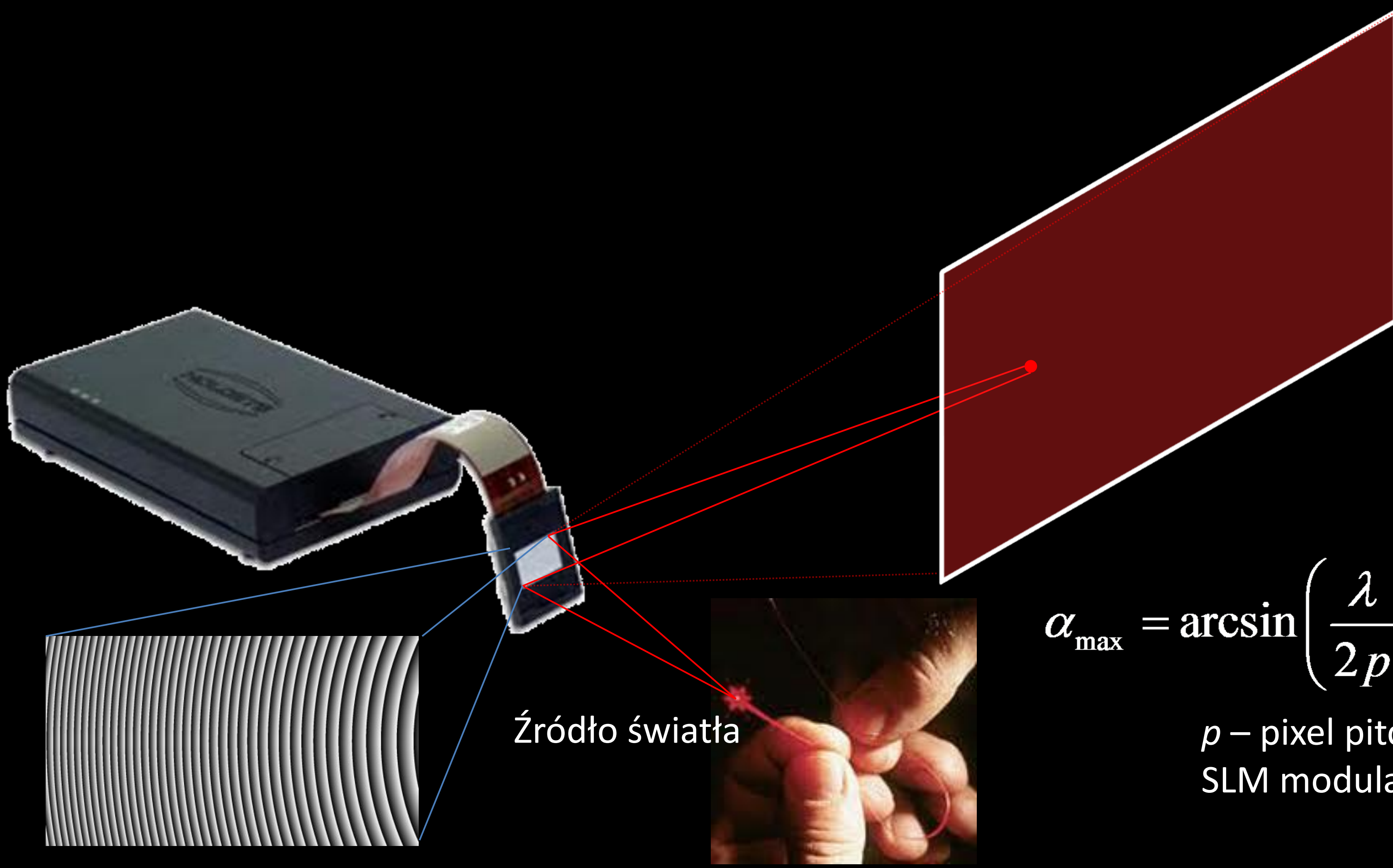
Electro-holography in a divergent beam



Phase of a convergent lens with focal length *f*, displayed on the SLM

$$\frac{1}{f} = \frac{1}{c} + \frac{1}{d}$$

Electro-holography in a divergent beam

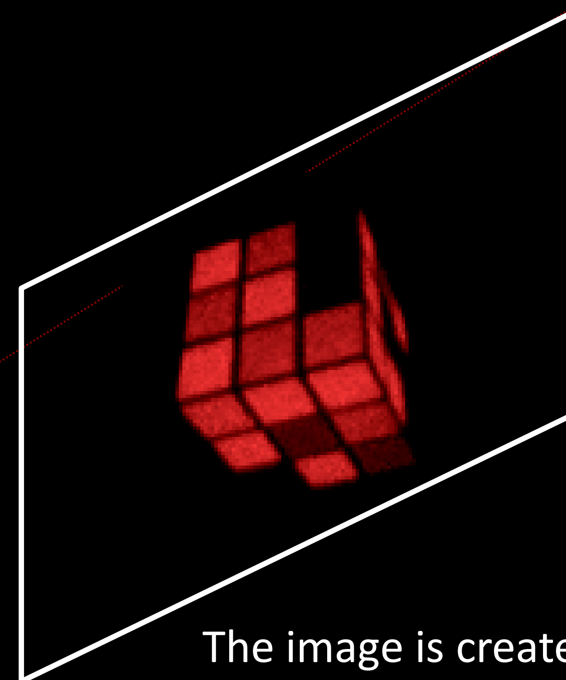


$$\alpha_{max} = \arcsin\left(\frac{\lambda}{2p}\right) \approx 10^{\circ}$$

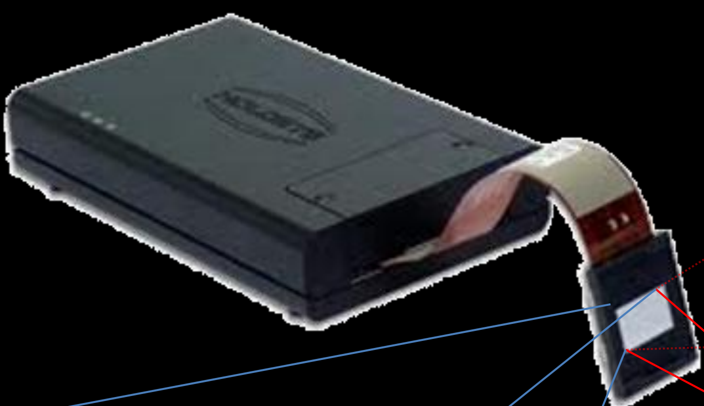
p – pixel pitch of the SLM modulator

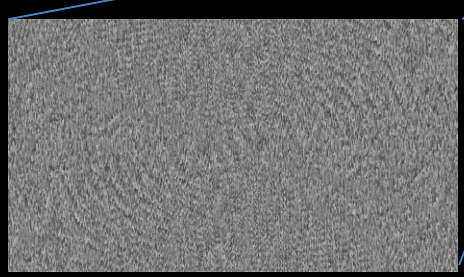
Phase of a convergent lens multiplied with a saw-tooth diffractive grating

Electro-holography in a divergent beam



Screen



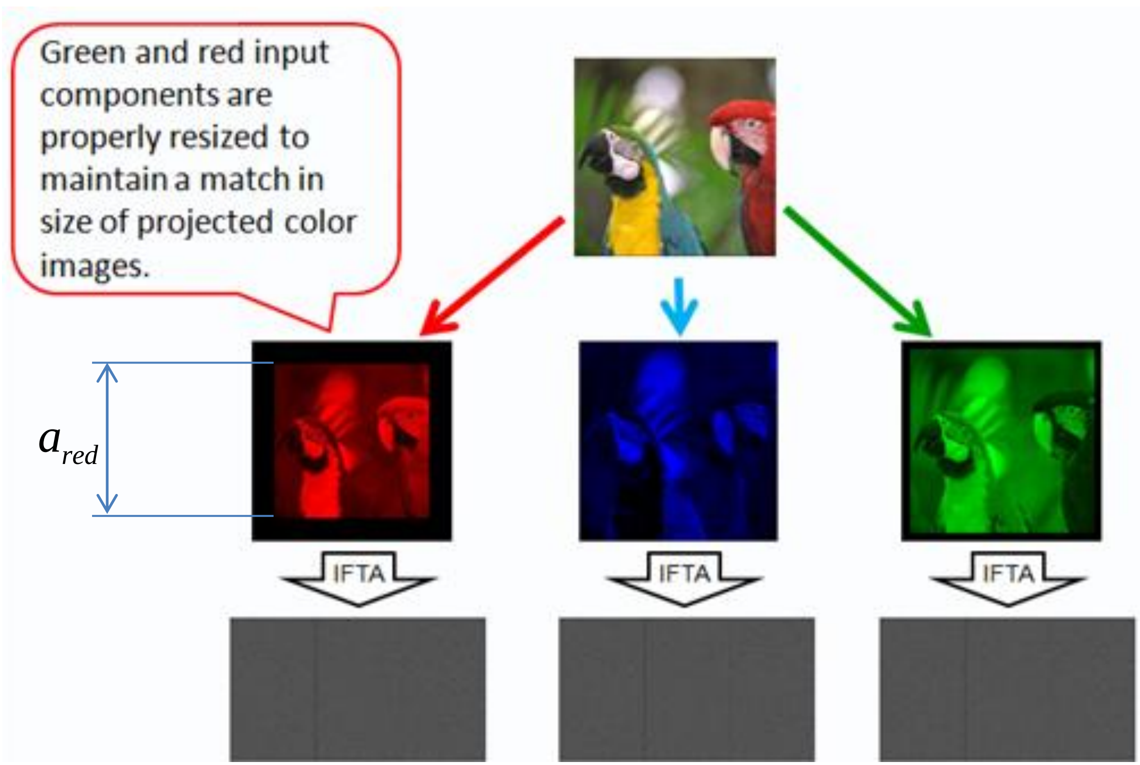


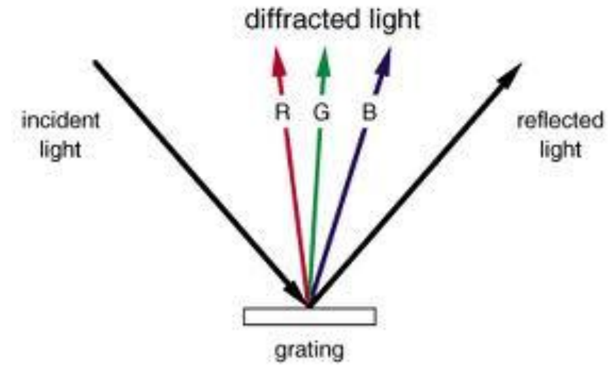
Light Source

The image is created by redirecting light to the right places, not by the selective absorption (conversion to heat).
Estimated efficiency: 25-30lm/W (current 15 lm/W)

Iterated Fourier hologram multiplied by a phase of a convergent lens

Algorithm of hologram calculation (1)



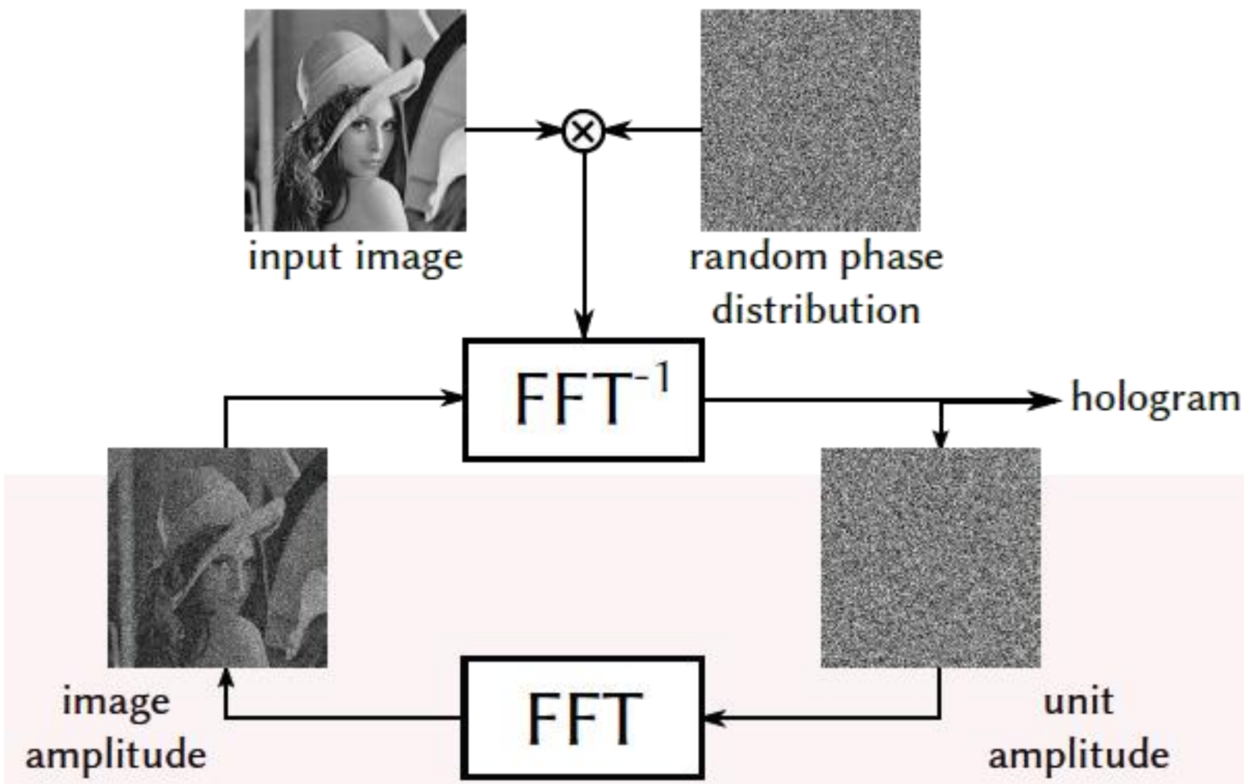


$$\alpha = \arcsin\left(\frac{\lambda}{2p}\right)$$

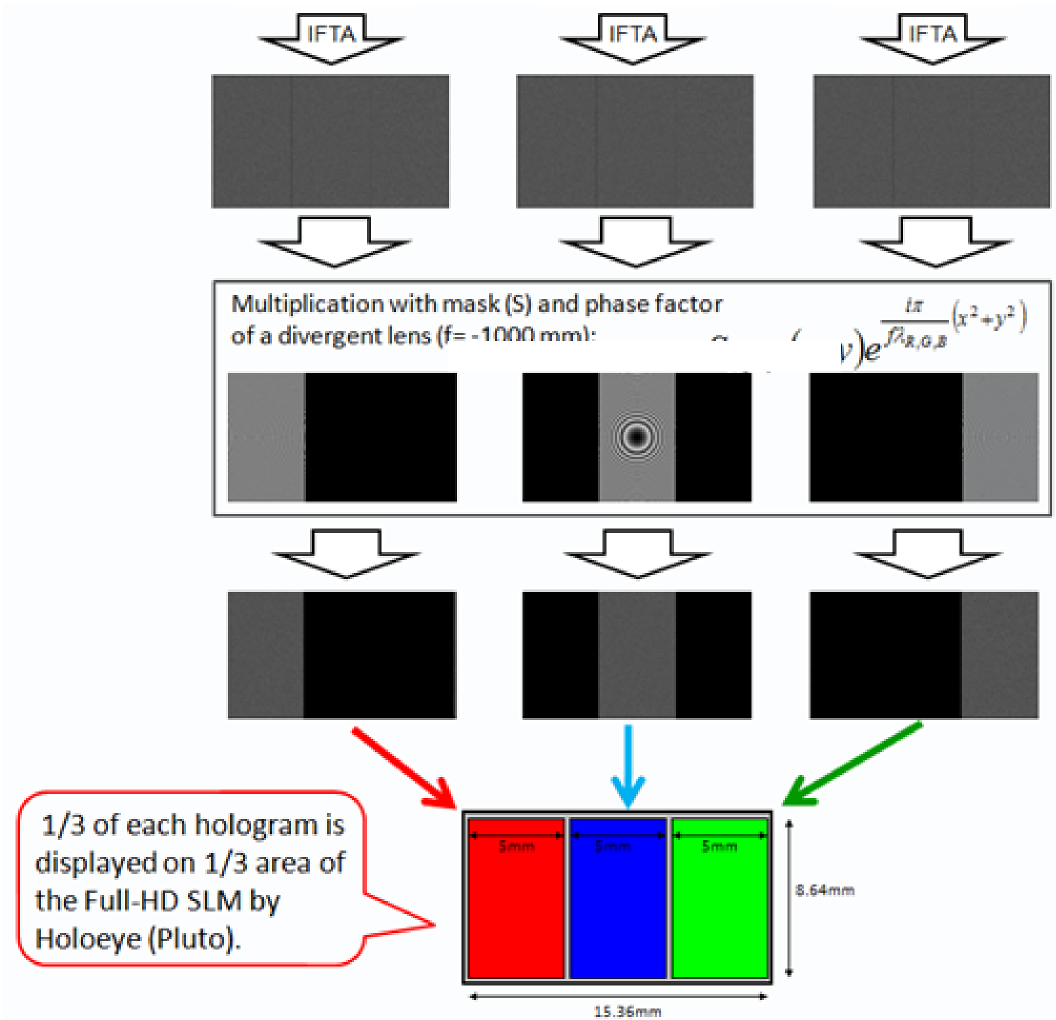
$$a_{red} / a_{green} / a_{blue} =$$
$$= \lambda_{blue} / \lambda_{green} / \lambda_{red} =$$
$$= 445nm / 532nm / 671nm$$

I. Ducin, K. Kakarenko, M. Makowski, A. Siemion, A. Siemion, J. Suszek, M. Sypek, D. Wojnowski, A. Kolodziejczyk, "Holographic color projection with additional phase factor to suppress zero diffractive order," Proc. SPIE 7746, 77460L (2010)

Iterative Fourier Transform Algorithm (IFTA) - modification of the Gerchberg-Saxton (GS) algorithm



Algorithm of hologram calculation (2)



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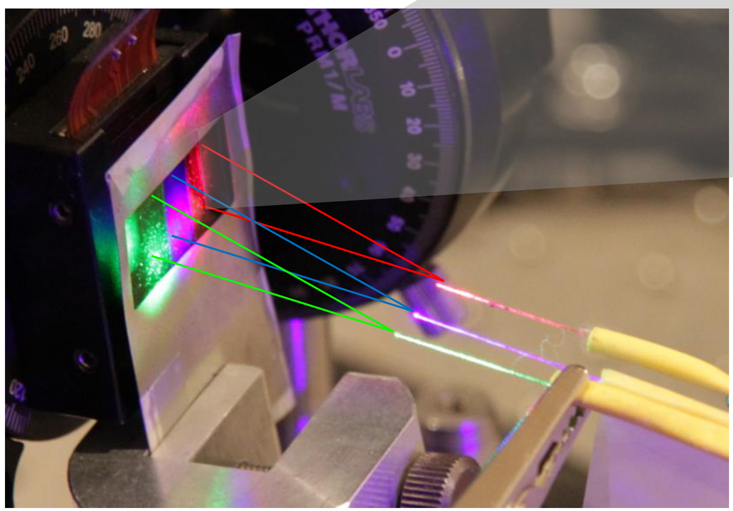
Holographic projection in color



Only 4 key elements of the optical setup
(3 fiber-ended lasers and SLM)

Lasers with single-mode fibers for:
671 nm; 532 nm; 445 nm.

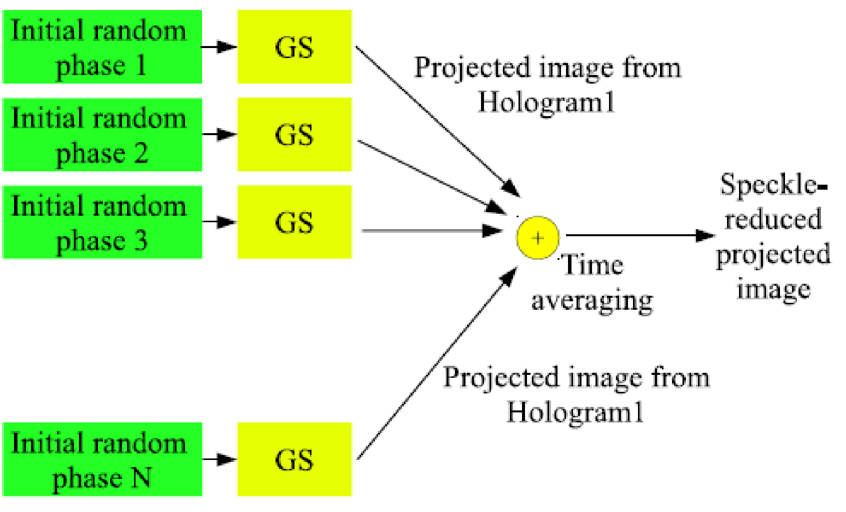
M. Makowski, I. Ducin, K. Kakarenko, J. Suszek, M. Sypek, A. Kolodziejczyk, "Simple holographic projection in color," Opt. Express 20, 25130-25136 (2012).

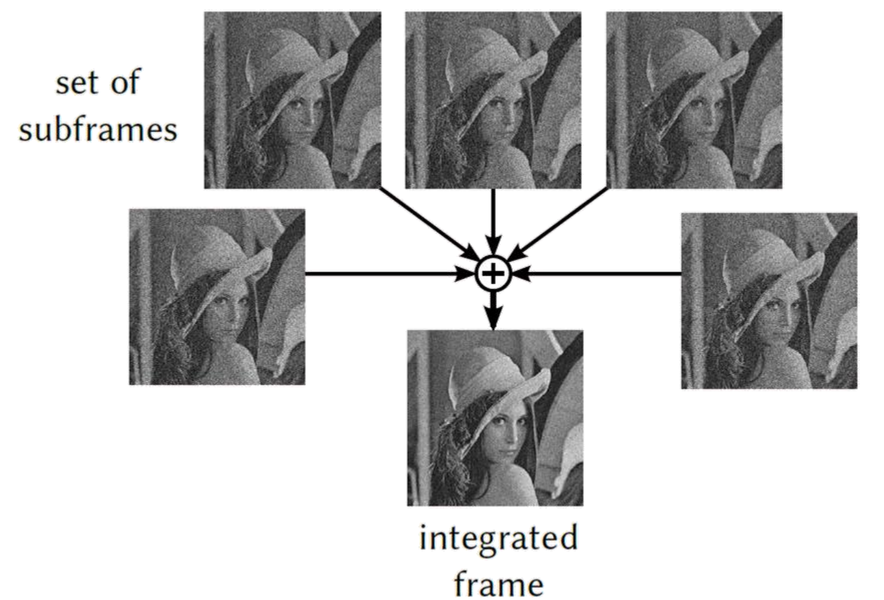
Experimental results

M. Makowski, I. Ducin, K. Kakarenko, J. Suszek, M. Sypek, A. Kolodziejczyk, "Simple holographic projection in color," Opt. Express 20, 25130-25136 (2012).

Noise reduction

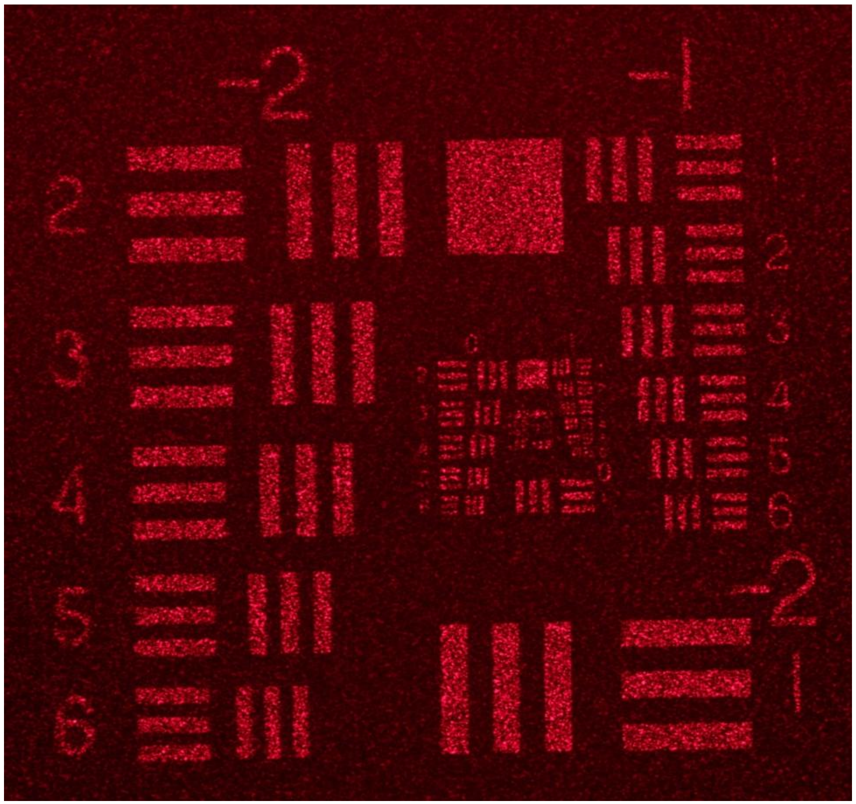
- Time Domain Random Phase (TDRP):
  Integration of intensity images formed with different initial random phase
- Use of time integration capability of human eyes and light detectors



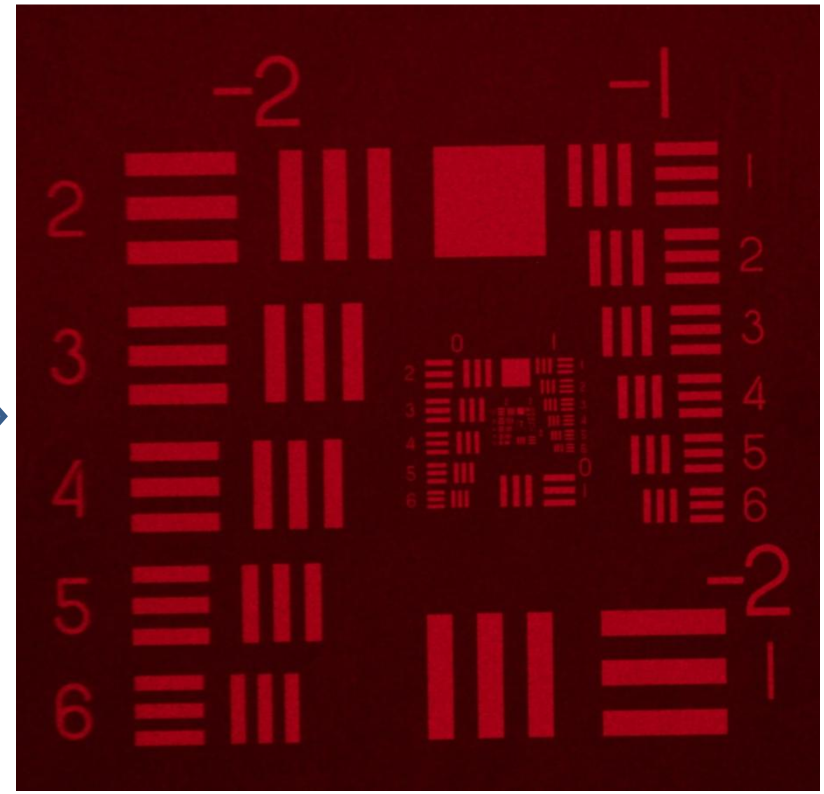


T. Shimobaba, M. Makowski, T. Kakue, M. Oikawa, N. Okada, Y. Endo, R. Hirayama, and T. Ito, "Lensless zoomable holographic projection using scaled Fresnel diffraction," Opt. Express. 21, 25285-25290 (2013).

Noise reduction



1 image

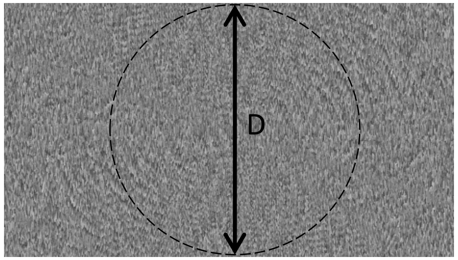


Integration of 25 images

K. Kakarenko, I. Ducin, M. Makowski, A. Siemion, A. Siemion, J. Suszek, M. Sypek, D. Wojnowski, and A. Kolodziejczyk, Proc. SPIE 7746, 77460N (2010).

Pixel separation method

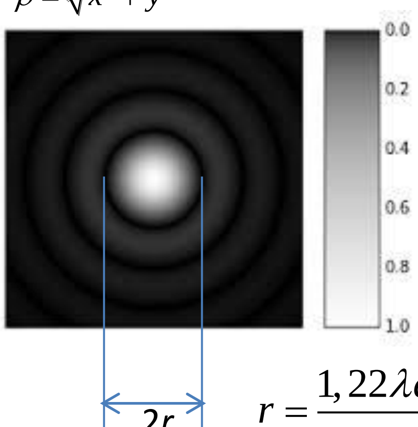
Phase hologram on the SLM:



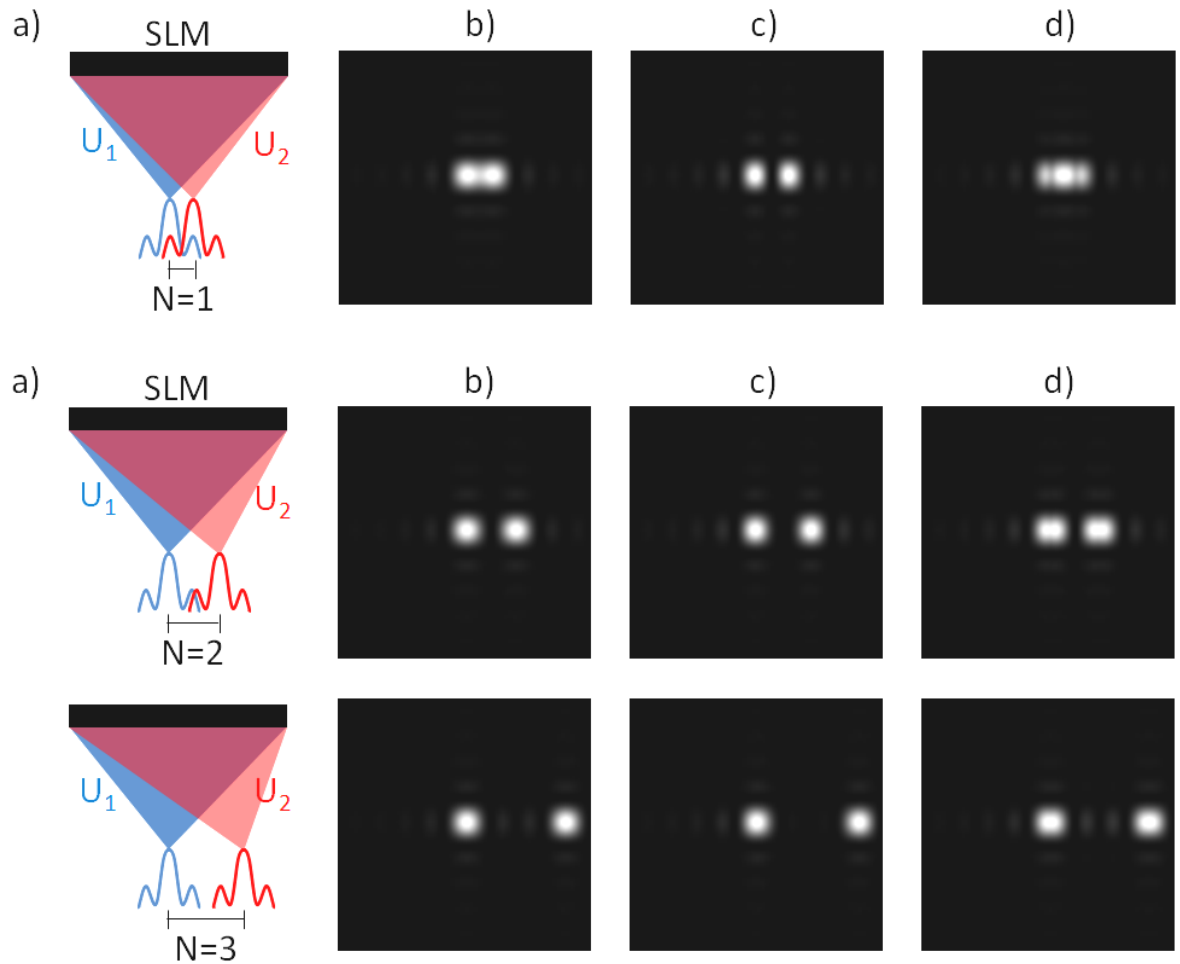
Point Spread Function, PSF
at the screen:

$$I(x,y) = I_0\left[\frac{2J_1(\pi D\rho/\lambda d)}{\pi D\rho/\lambda d}\right]^2,$$

$$\rho = \sqrt{x^2+y^2}$$



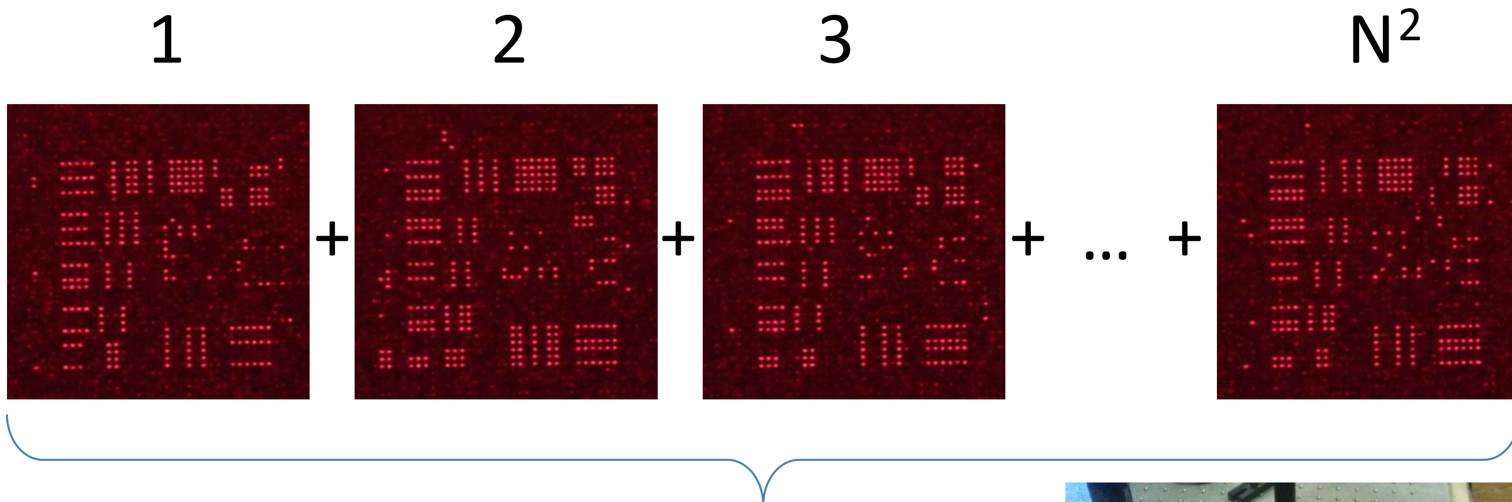
$$r = \frac{1,22\lambda d}{D}$$

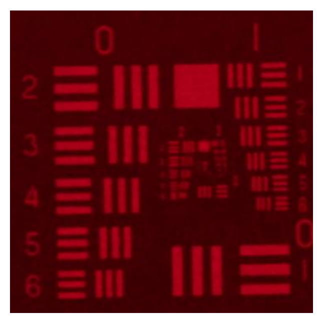


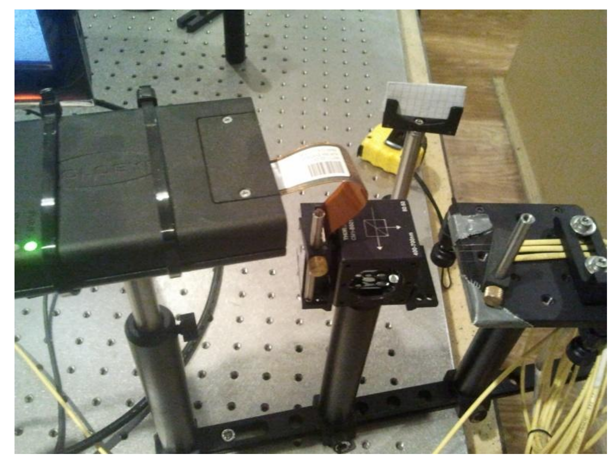
M. Makowski, "Minimized speckle noise in lens-less holographic projection by pixel separation," Opt. Express 21, 29205-29216 (2013)

Y. Takaki and M. Yokouchi, "Speckle-free and grayscale hologram reconstruction using time-multiplexing technique," Opt. Express 19, 7567-7579 (2011)

Pixel separation method







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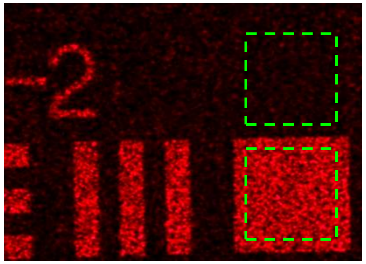
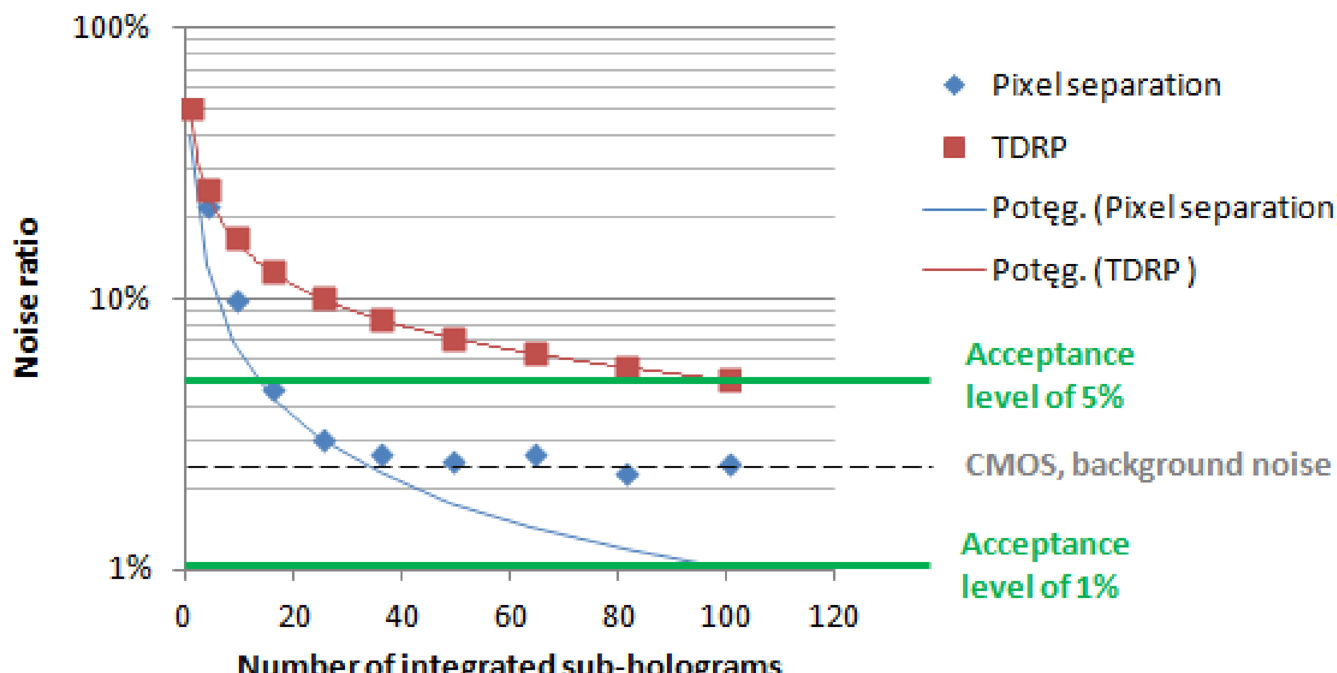


I_{2avg}

I_{1avg}, σ_1 (standard deviation of intensity)

Noise: $N = \sigma_1 / I_{1avg}$

Contrast: $C = I_{1avg} / I_{2avg}$



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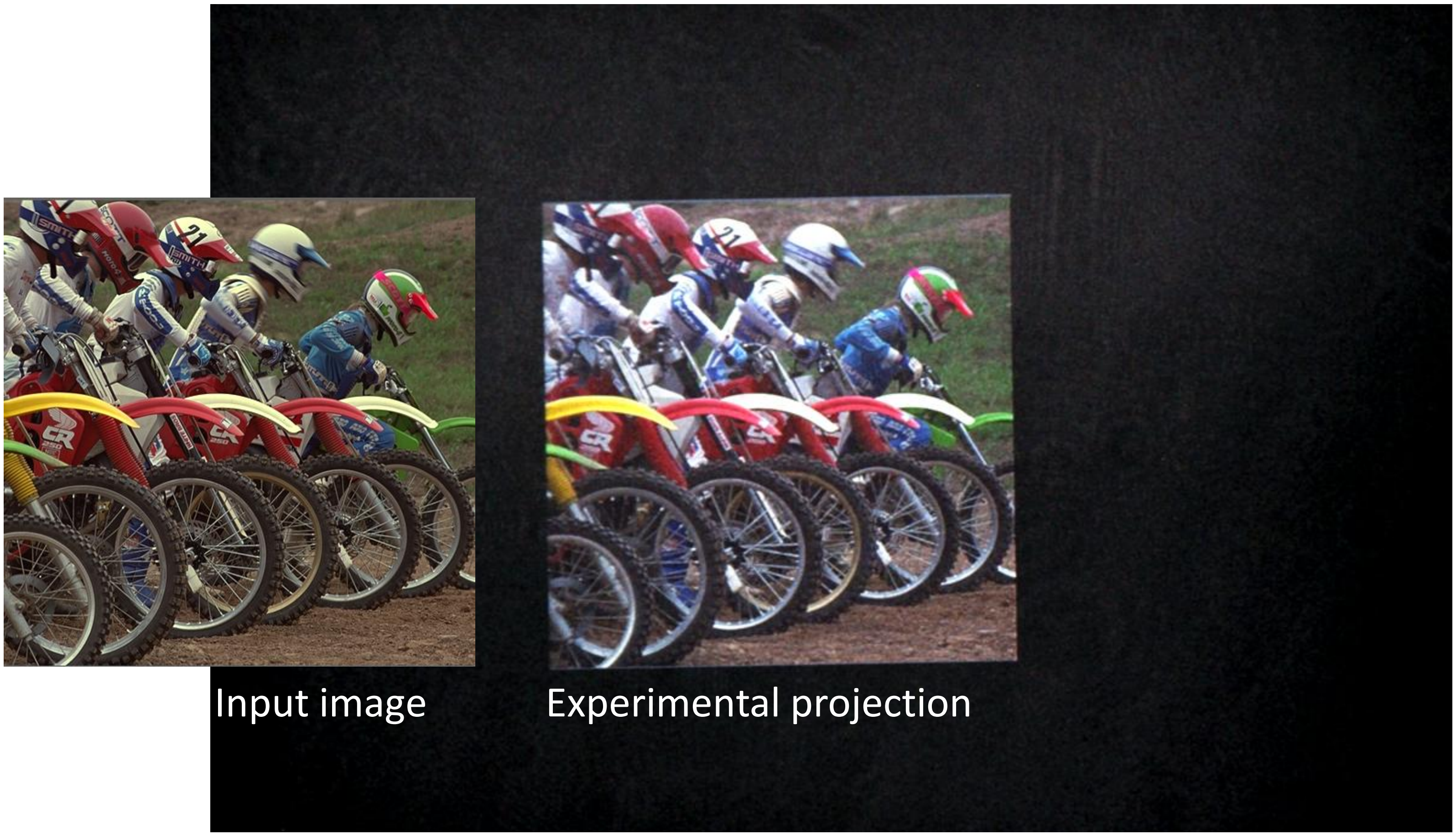
Latest experimental results



M. Makowski, "Minimized speckle noise in lens-less holographic projection by pixel separation," Opt. Express 21, 29205-29216 (2013)

Calculation speed

- 2048x1024 pixels, 8-bit

	Intel Core i3-3217U	nVidia 710M	nVidia GTX660
iter.	FPS	FPS	FPS
0	6,4	45	84
1	3,8	23	69
2	2,8	16	59
4	1,8	9,4	44
8	1,0	5,3	30
16	0,55	2,8	18

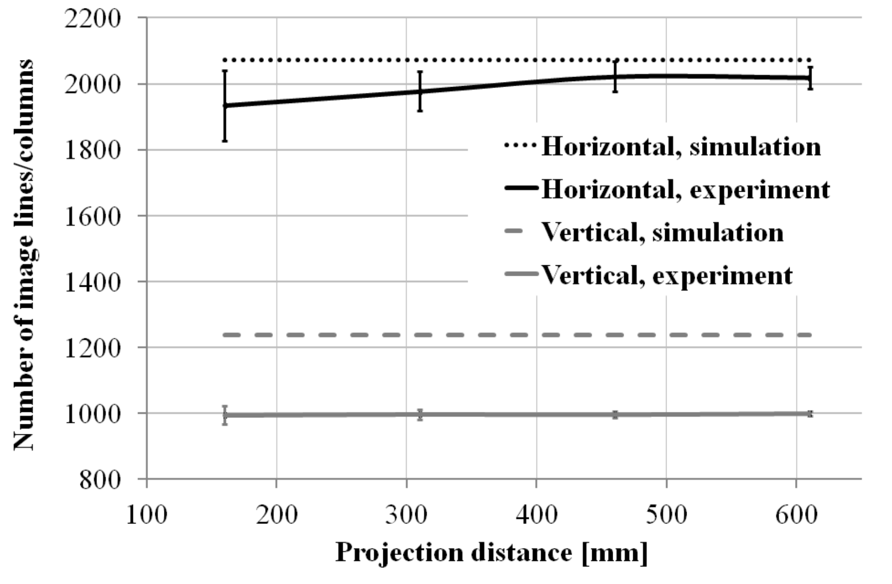
Latest experimental results

Stepless and lossless zoom with no moving parts

T. Shimobaba, M. Makowski, T. Kakue, M. Oikawa, N. Okada, Y. Endo, R. Hirayama, and T. Ito, "Lensless zoomable holographic projection using scaled Fresnel diffraction," Opt. Express. 21, 25285-25290 (2013)

Resolution

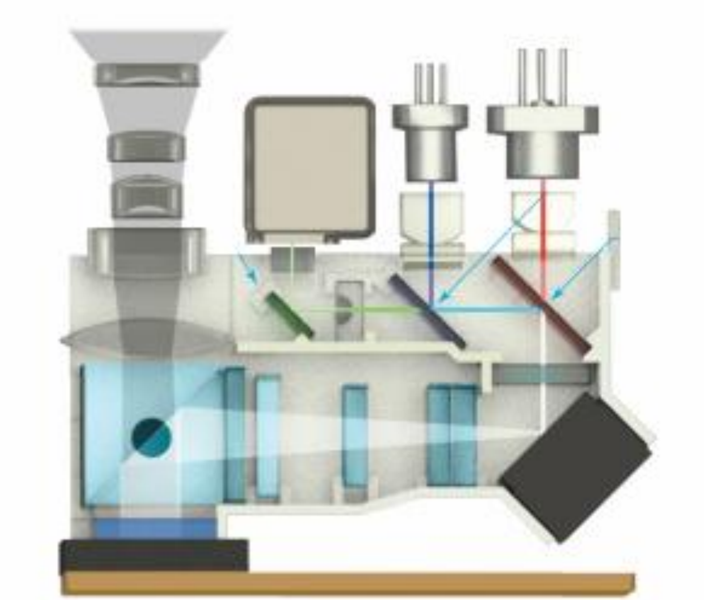
- Experimental resolution of 2020x1000 points was achieved



- Spatial Light Modulator: 3184x2160 pixels, 3.74 µm pixel pitch

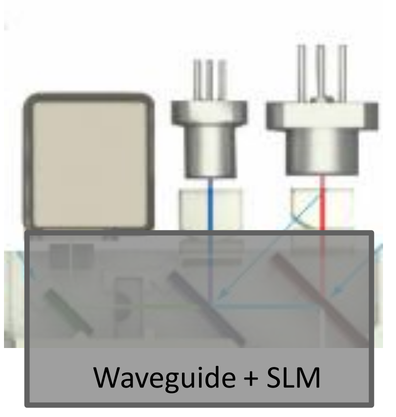
Miniaturization possibility

Classic pico-projection



Compound Photonics HD5 – smallest pico-projector, ca. 4.1 cm^3

Holographic pico-projection



Concept scheme, ca. 3 cm^3

Application-based approach

To create a light distribution at the desired projection plane:

- ❑ with efficient light sources
- ❑ without light losses in the lightpath
- ❑ without mechanical focusing/zoom
- ❑ without geometric and chromatic aberrations
- ❑ in a miniaturized setup (several cm^3)
- ❑ with wide color gamut
- ❑ in real time
- ❑ with wide angle projection
- ❑ in a safe way

Solution #1: classic projector

To create a light distribution at the desired projection plane:

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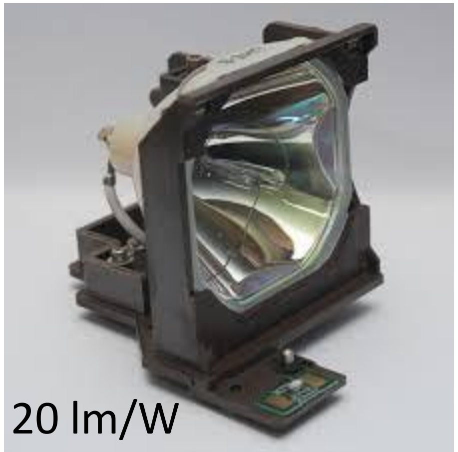
Overall efficiency: 3-10%



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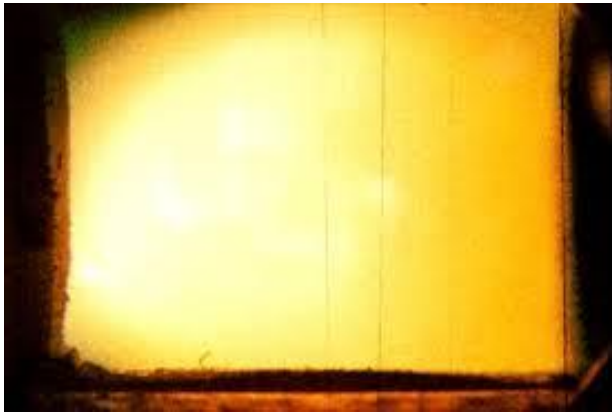

Overall efficiency: 4,8 lm/W

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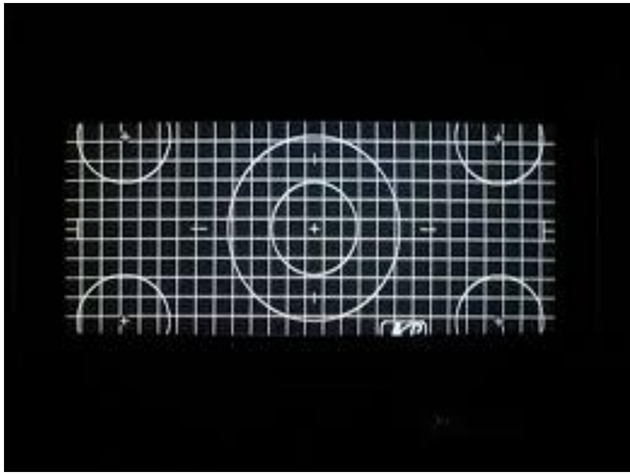

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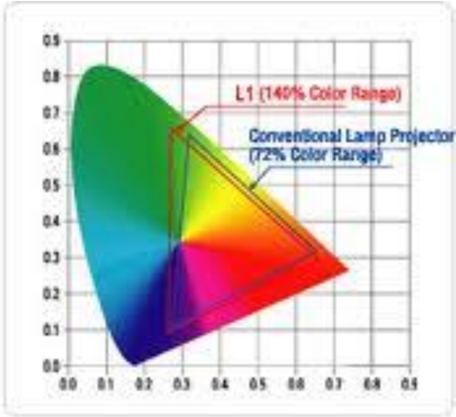

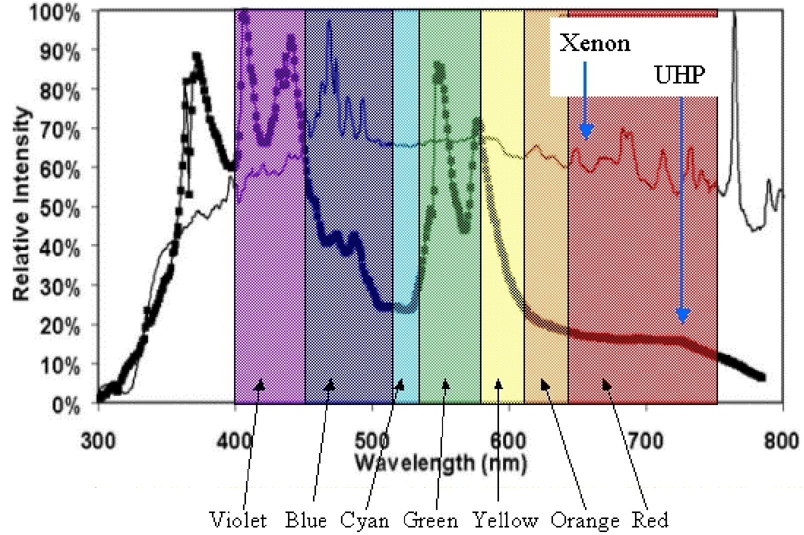

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Solution #2: LED pico-projector

To create a light distribution at the desired projection plane:

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>100 lm/W
(halogen bulb: 20lm/W)

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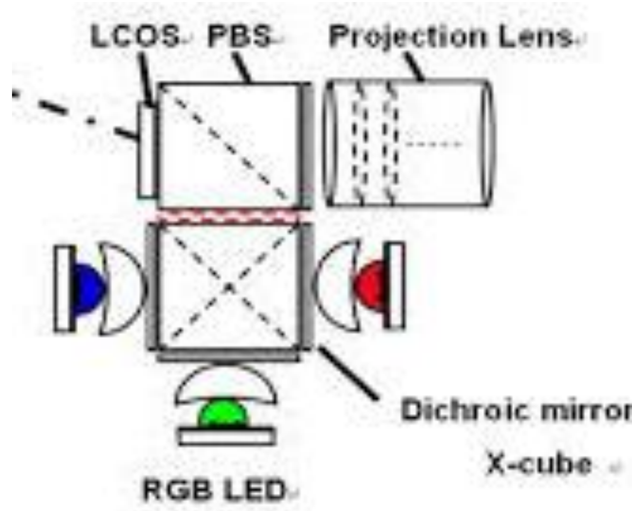

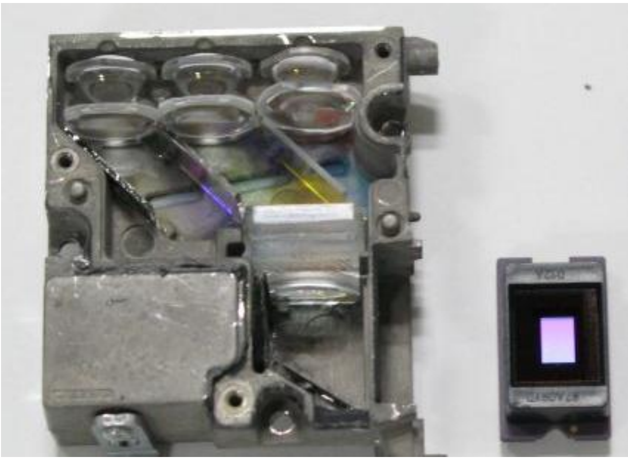

Overall efficiency: 15 lm/W

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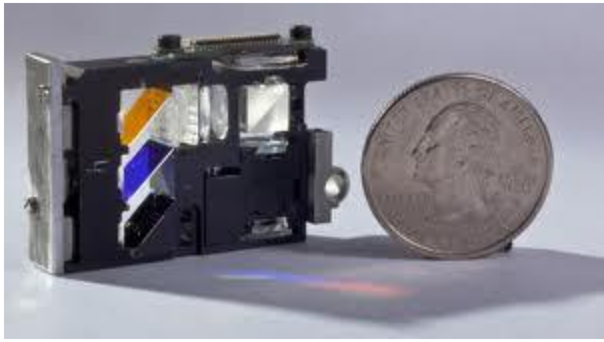

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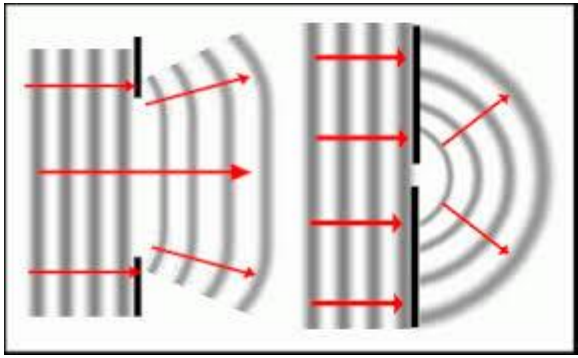

Diffraction on a small aperture

Solution #2: LED pico-projector

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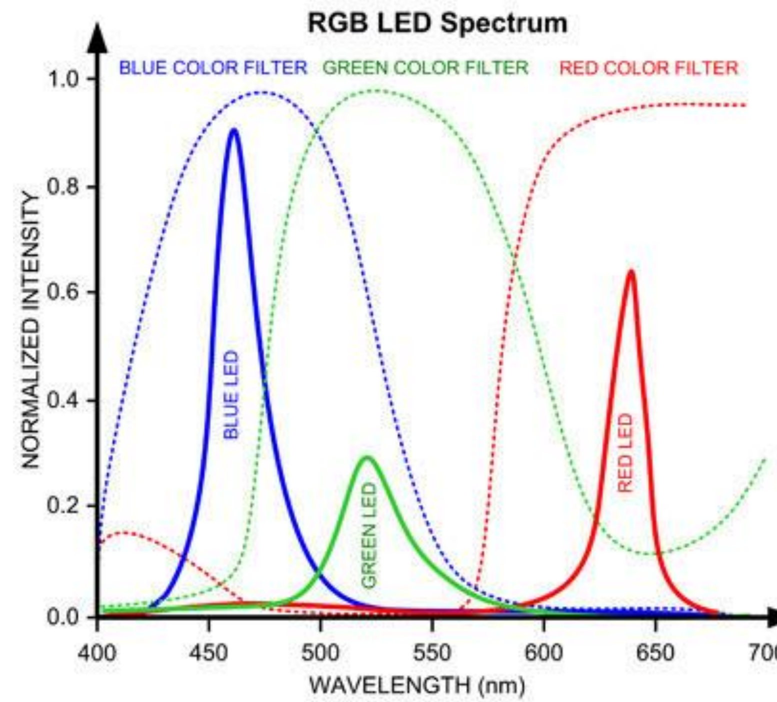

Solution #3: Laser Beam Scanning (LBS)

To create a light distribution at the desired projection plane:

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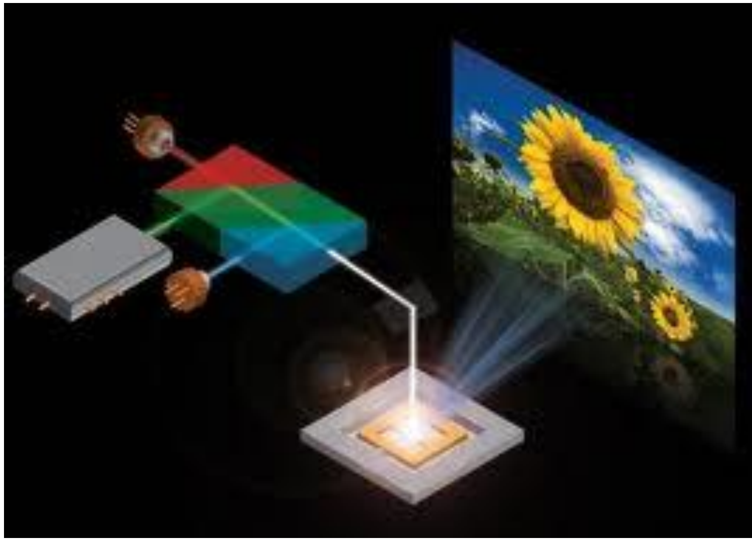

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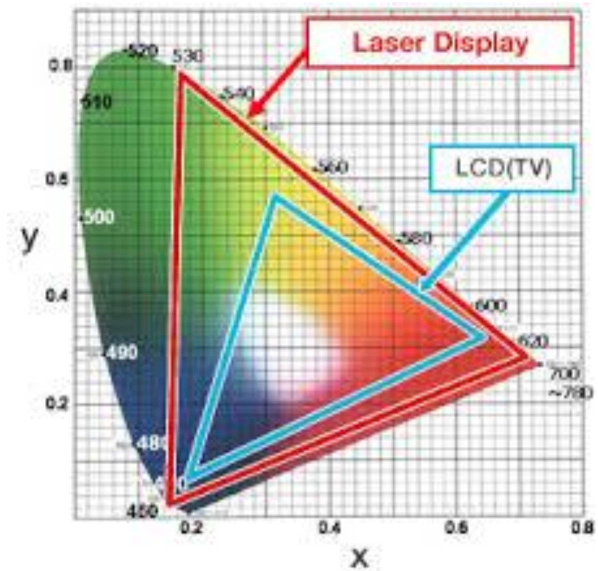

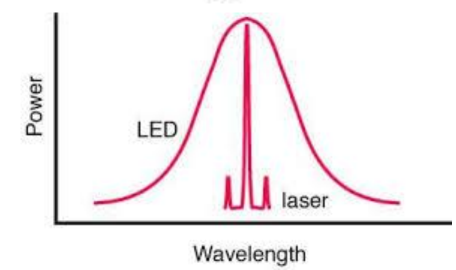

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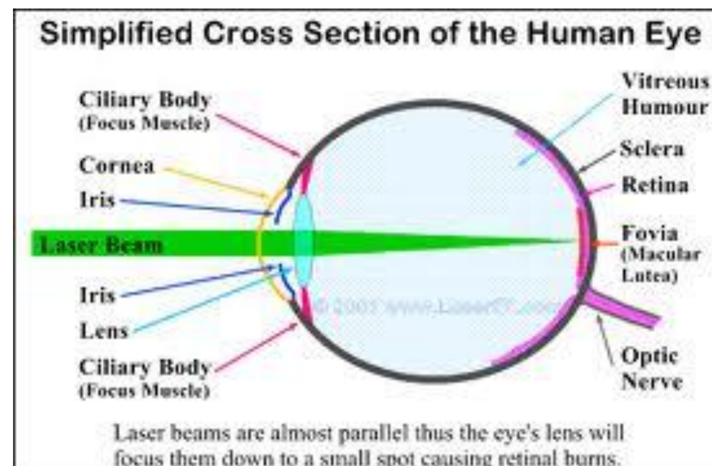
- ✘ with wide angle projection
- ✘ in a safe way

Class II max



Comparison of projection solutions

To create a light distribution at the desired projection plane:

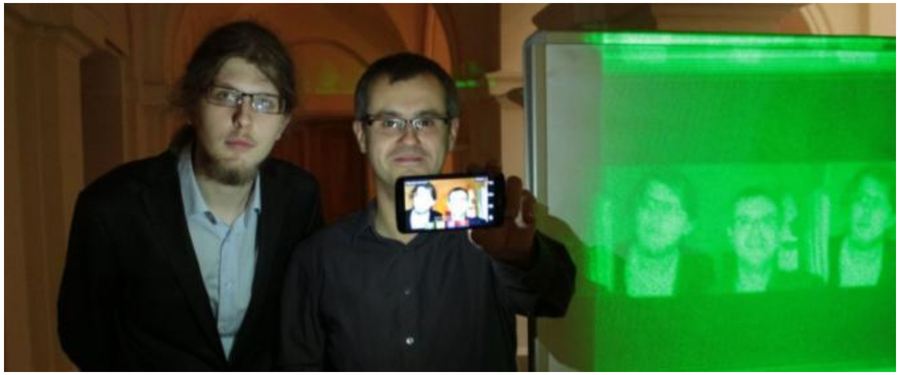
	1	2	3
❑ with efficient light sources	✗	✓	✓
❑ without light losses in the lightpath	✗	✗	✓
❑ without mechanical focusing/zoom	✗	✗	✓
❑ without geometric and chromatic aberrations	✗	✗	✗
❑ in a miniaturized setup (several cm^3)	✗	✓	✓
❑ with wide color gamut	✗	✗	✓
❑ in real time	✓	✓	✗
❑ with wide angle projection	✓	✓	✗
❑ in a safe way	✓	✓	✗

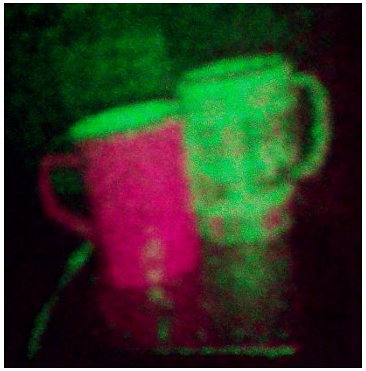
Comparison of projection solutions

To create a light distribution at the desired projection plane:

	1	2	3	Holo
❑ with efficient light sources	✗	✓	✓	✓
❑ without light losses in the lightpath	✗	✗	✓	✓
❑ without mechanical focusing/zoom	✗	✗	✓	✓
❑ without geometric and chromatic aberrations	✗	✗	✗	✓
❑ in a miniaturized setup (several cm^3)	✗	✓	✓	✓
❑ with wide color gamut	✗	✗	✓	✓
❑ in real time	✓	✓	✗	✓
❑ with wide angle projection	✓	✓	✗	✗✓
❑ in a safe way	✓	✓	✗	✓

- Tonight at 7PM: Gala in the Physics Building, Warsaw University of Technology
- First show of the real-time color holographic projection





Thank you!

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Further reading:

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