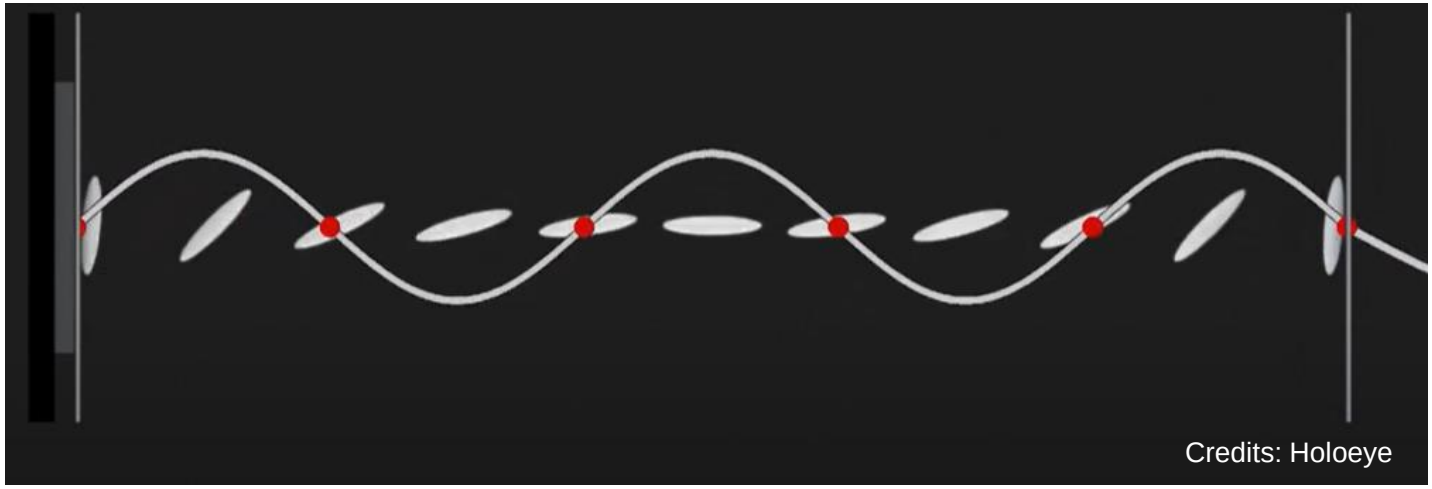
Implementation of a compact optical architecture for visual psychophysical tests based on spatial light modulators



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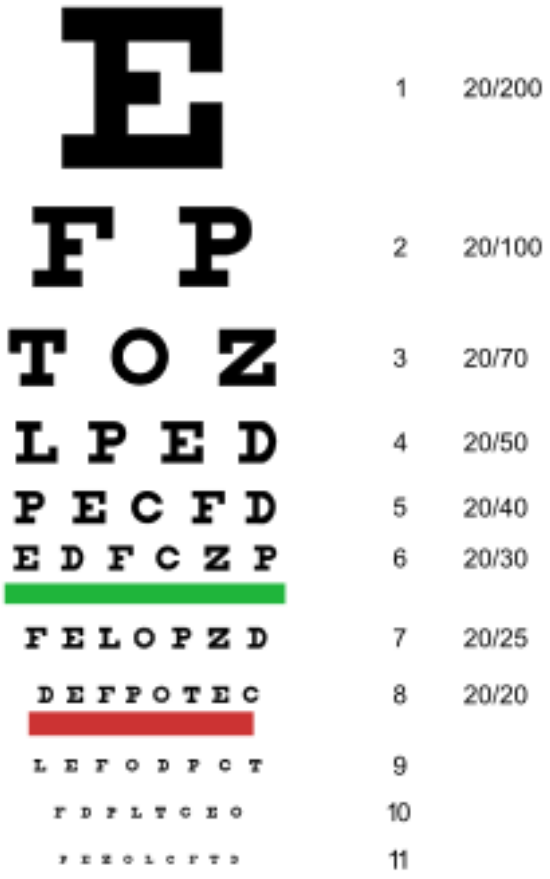
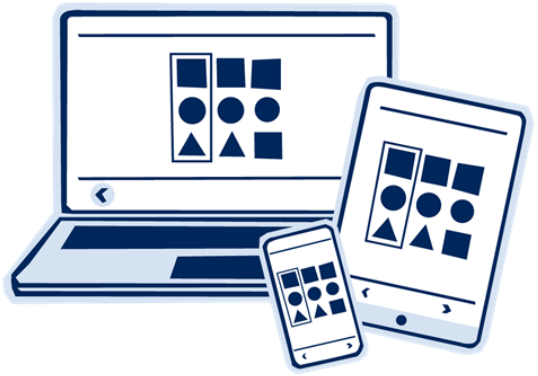
Psychophysical tests in Optometry

Psychophysical tests are the core of optometry: how to correlate a physical stimulus with a subjective perception?





What about Spatial Light Modulators (SLM)?

Different applications and usage:

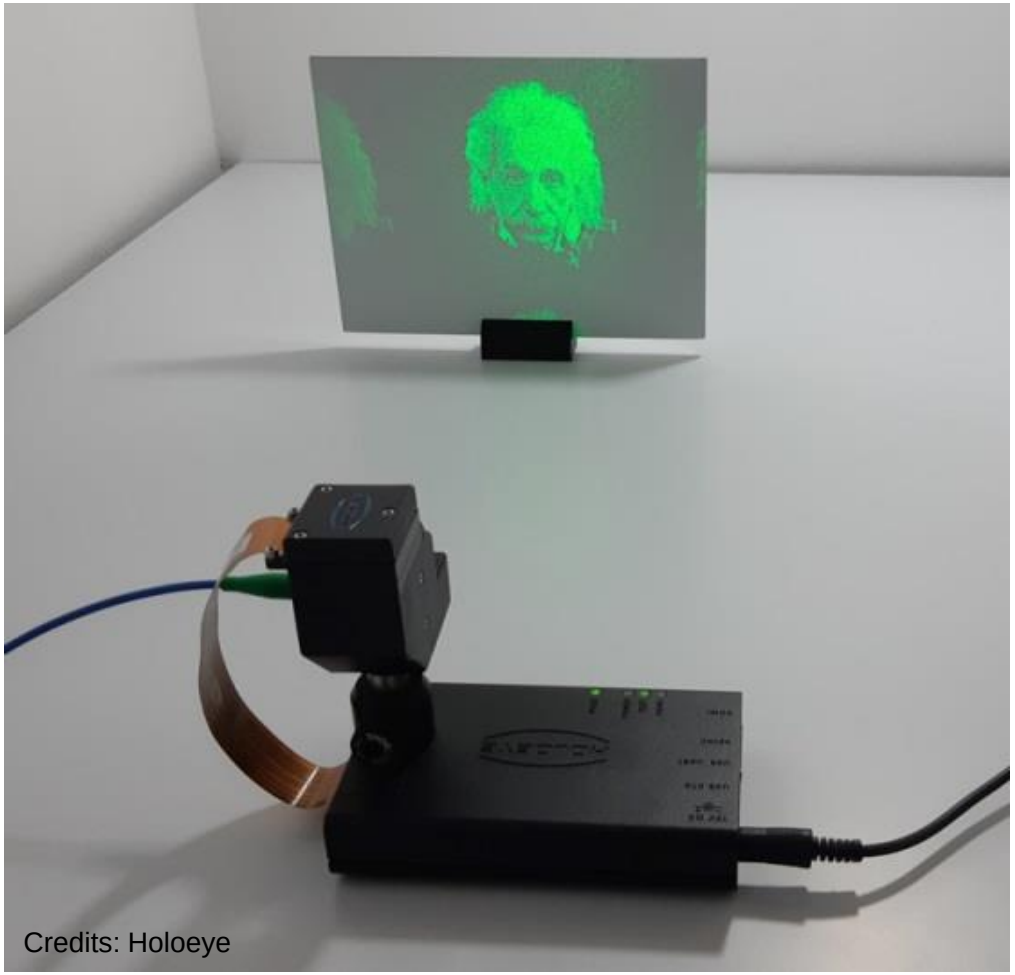
- Imaging & Projection
- Display Applications
- Holography (display, recording, security)
- Holographic Projection
- Wavelengths Selective Switching
- Beam splitting and steering
- Laser Beam Shaping

Advantages:

- **Versatility (infinite optical elements)**
- **Dynamicity**

Drawbacks:

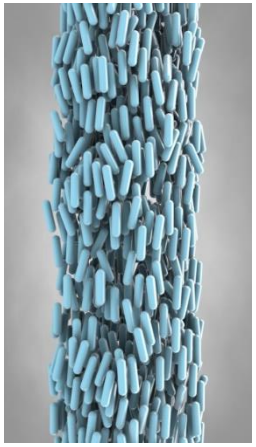
- High costs
- Slow (max 400 Hz)

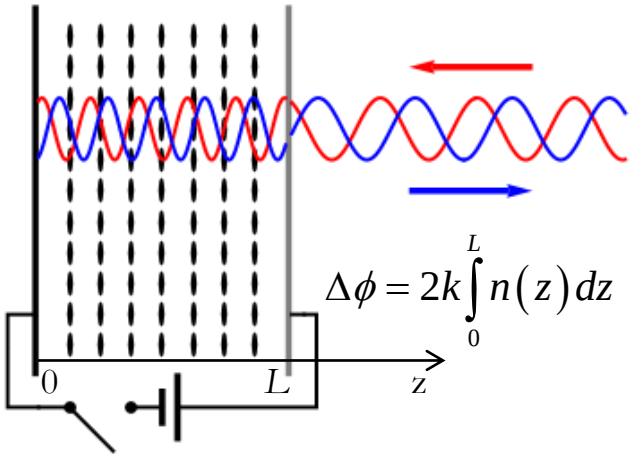


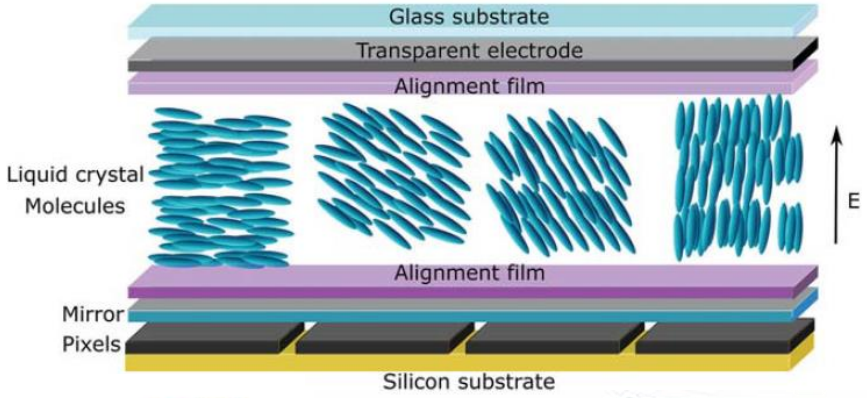
Credits: Holoeye

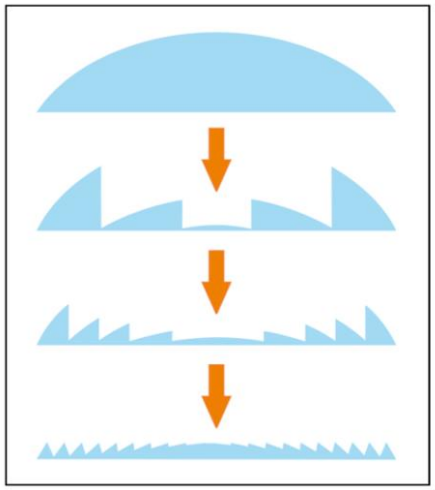
Spatial light modulators (SLM)

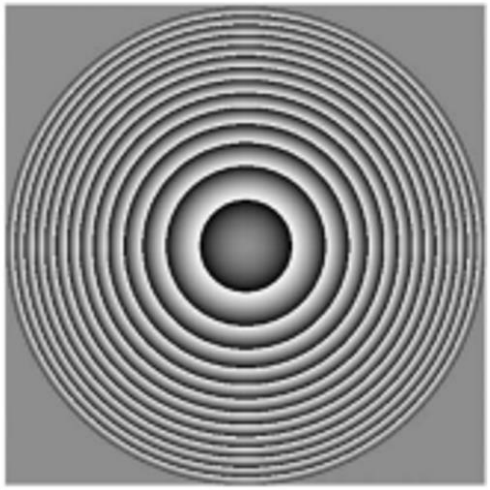
By controlling the electric field which is experienced by a thin layer of **nematic liquid crystals**, it is possible to change the integrated refractive index, and therefore the phase:

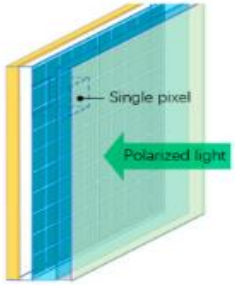


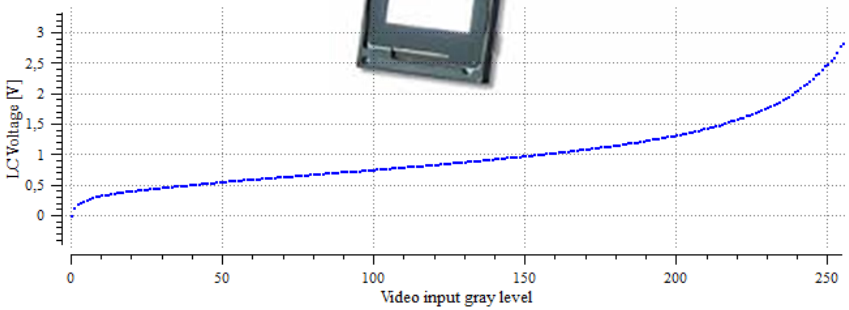








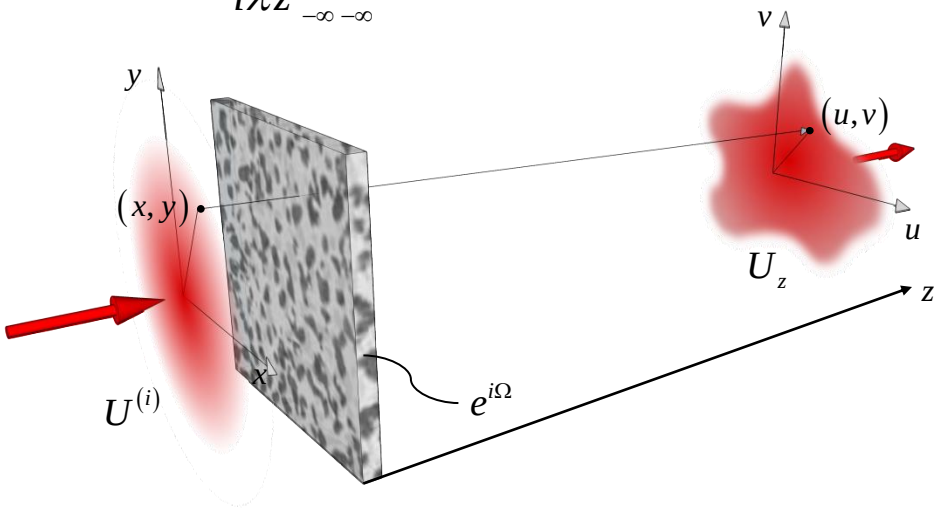


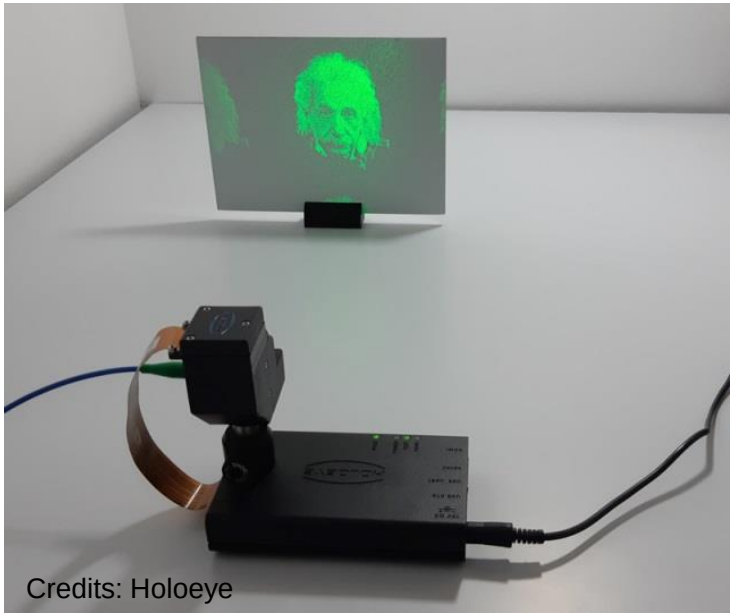


Light manipulation with SLM

In the paraxial regime, the propagation of a beam after passing through a phase-shaping region is described by the **Fresnel-Kichhoff diffraction integral**:

$$U_z(u,v) = \frac{e^{ikz}}{i\lambda z}\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} U^{(i)}(x,y)\, e^{i\Omega(x,y)}\, e^{-ik\frac{xu+yv}{z}}\, dxdy$$





The integral is a 2D Fourier Transform (FT) in the spatial coordinates, then the pattern to be uploaded on the SLM is the Fourier transform of the image we want to generate.

$$U_z \propto FT\left[U^{(i)} e^{i\Omega}\right]$$

Due to design constraints (*e.g.*, phase-only SLM pattern), iterative Fourier Transform algorithms (IFTA) (*e.g.*, Gerchberg-Saxton) are applied to converge to an optimal SLM pattern.

The experimental setup

PLUTO-2.1-VIS-014 SLM (HoloEye)

Display Type:	Reflective LCOS (Phase Only)
Resolution:	1920 x 1080
Pixel Pitch:	8.0 µm
Fill Factor:	93 %
Active Area	15.36 x 8.64 mm (0.7″ Diagonal)
Addressing	8 Bit (256 Grey Levels)
Signal Formats	HDMI – HDTV Resolution
Input Frame Rate	60 Hz

Plug & play phase modulator controlled via standard graphics cards as an extended monitor device. The green color channel of the video signal is used for addressing 8-bit gray level patterns

Collimated Laser diode module (CPS180, Thorlabs): 635 nm, 1.0 mW

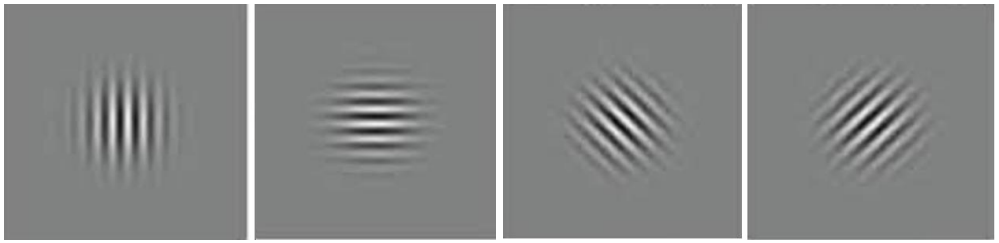
Tests targets and method

VISUAL ACUITY: Monoyer progression

Z Z Z Z Z Z Z Z Z

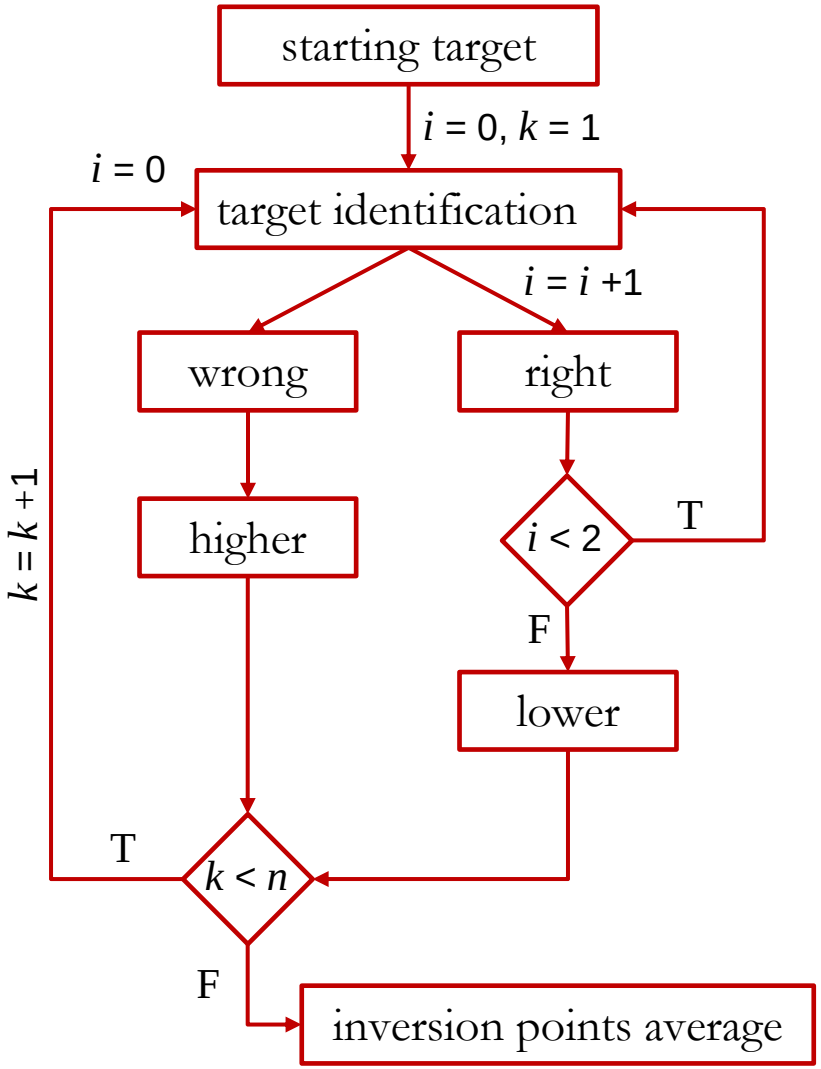
Snellen optotypes: C-D-E-F-L-O-P-T-Z
Distance 3 m. Trials: 30, decreasing size

CONTRAST SENSITIVITY: Gabor grating



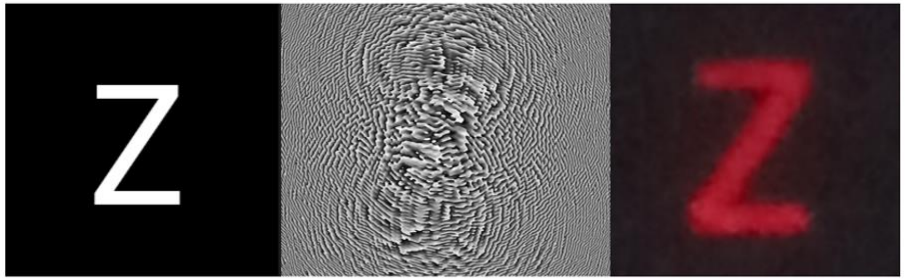
Fixed waist, 4 orientations
Distance: 1 m. Trials: 25, decreasing contrast

One-up two-down staircase:

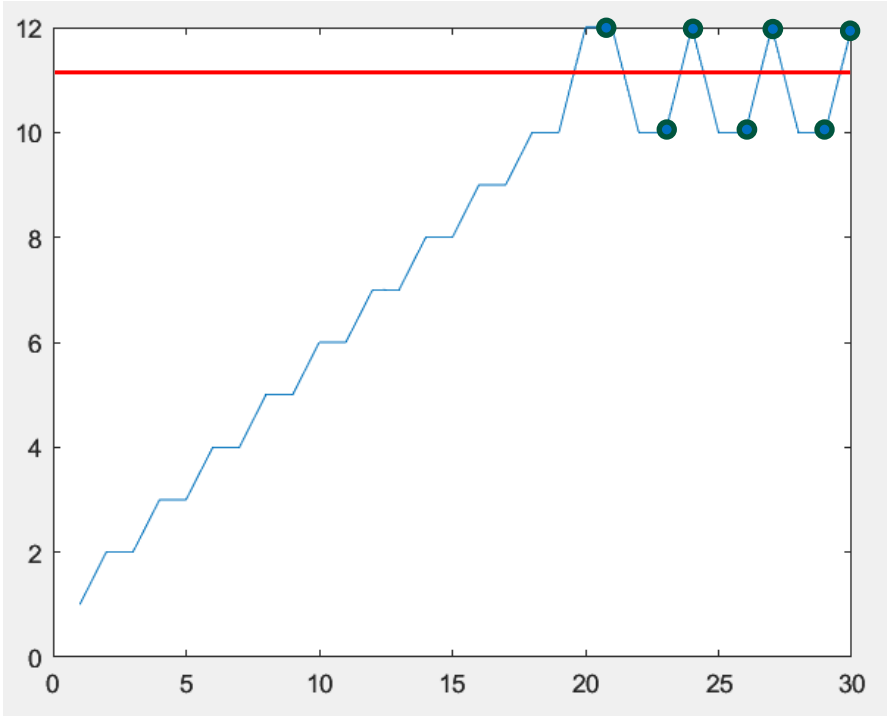


Testing VA and CS

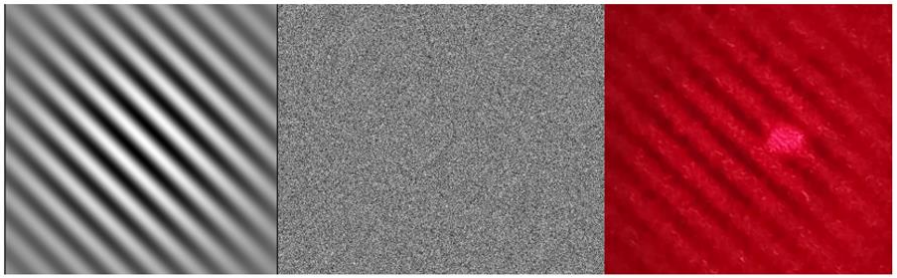
VISUAL ACUITY (VA)



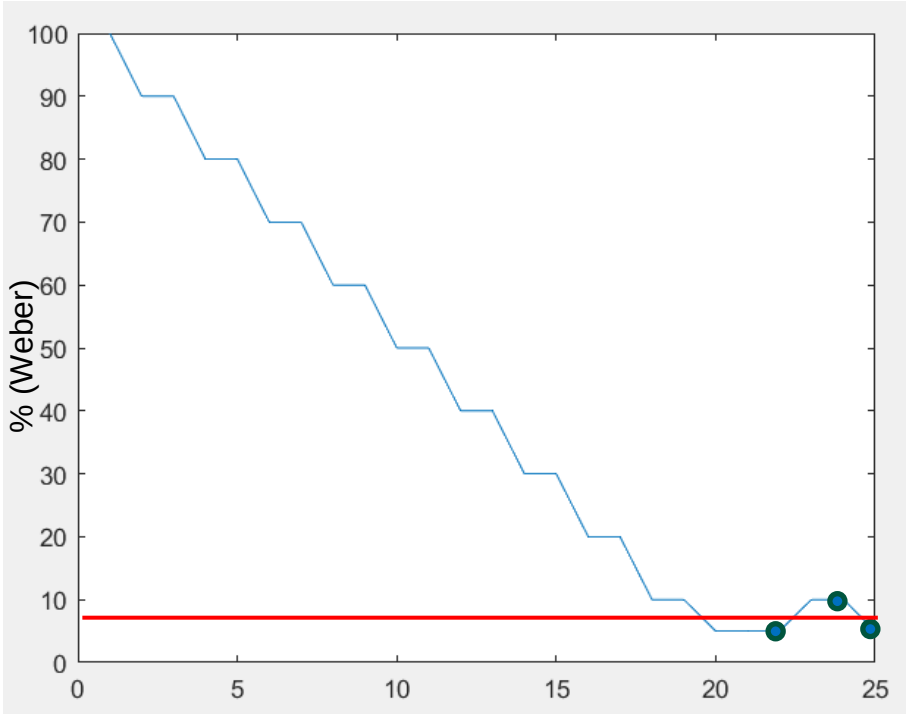
optotype | phase-only CGH (8-bit) | far-field



CONTRAST SENSITIVITY (CS)

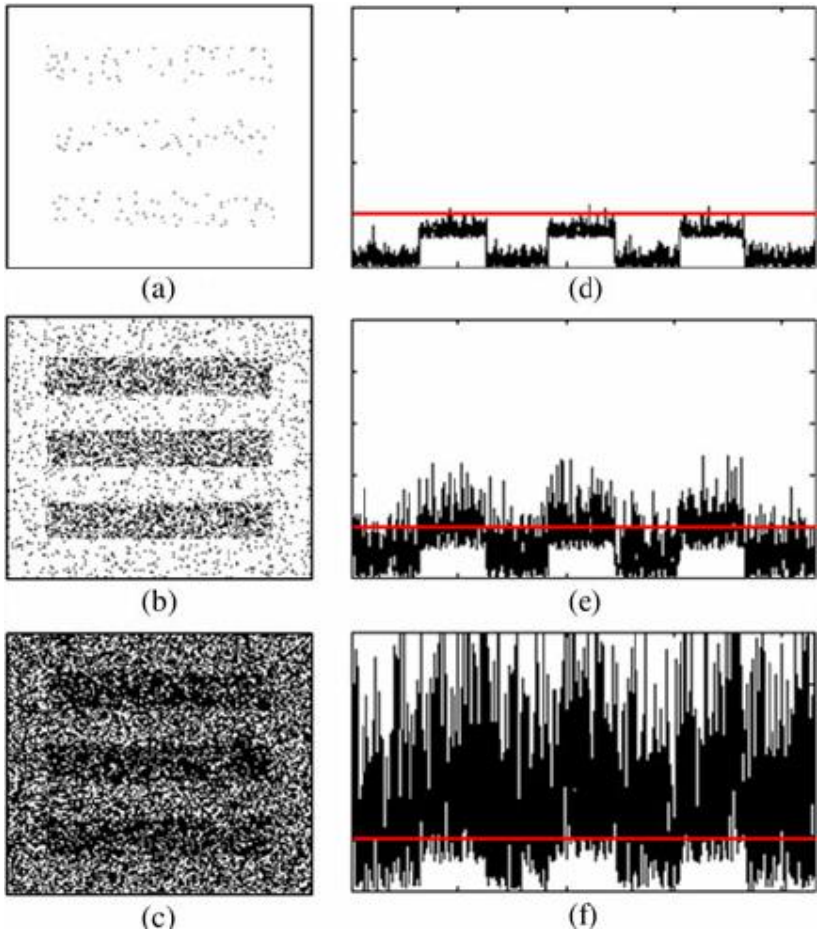


Gabor grating | phase-only CGH (8-bit) | far-field

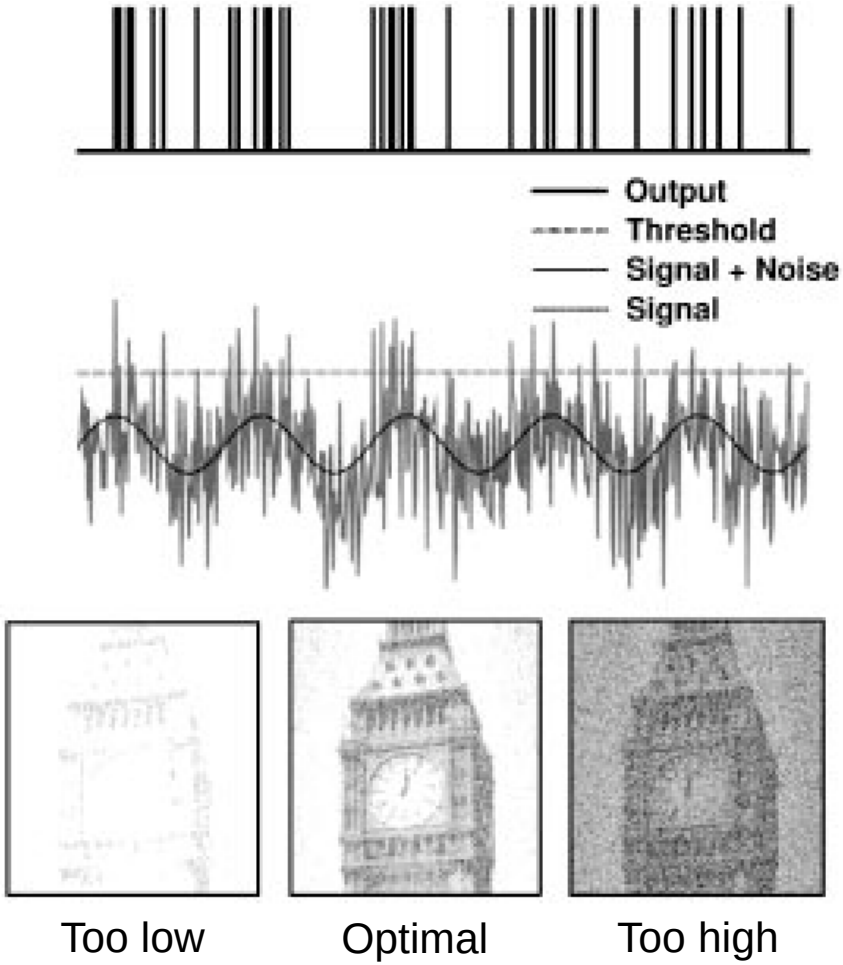


Application to stochastic resonance

Noise can improve the sensitivity in non-linear systems (e.g., effects in climatology).
Applications to vision science: there is an optimal level of noise for image perception.

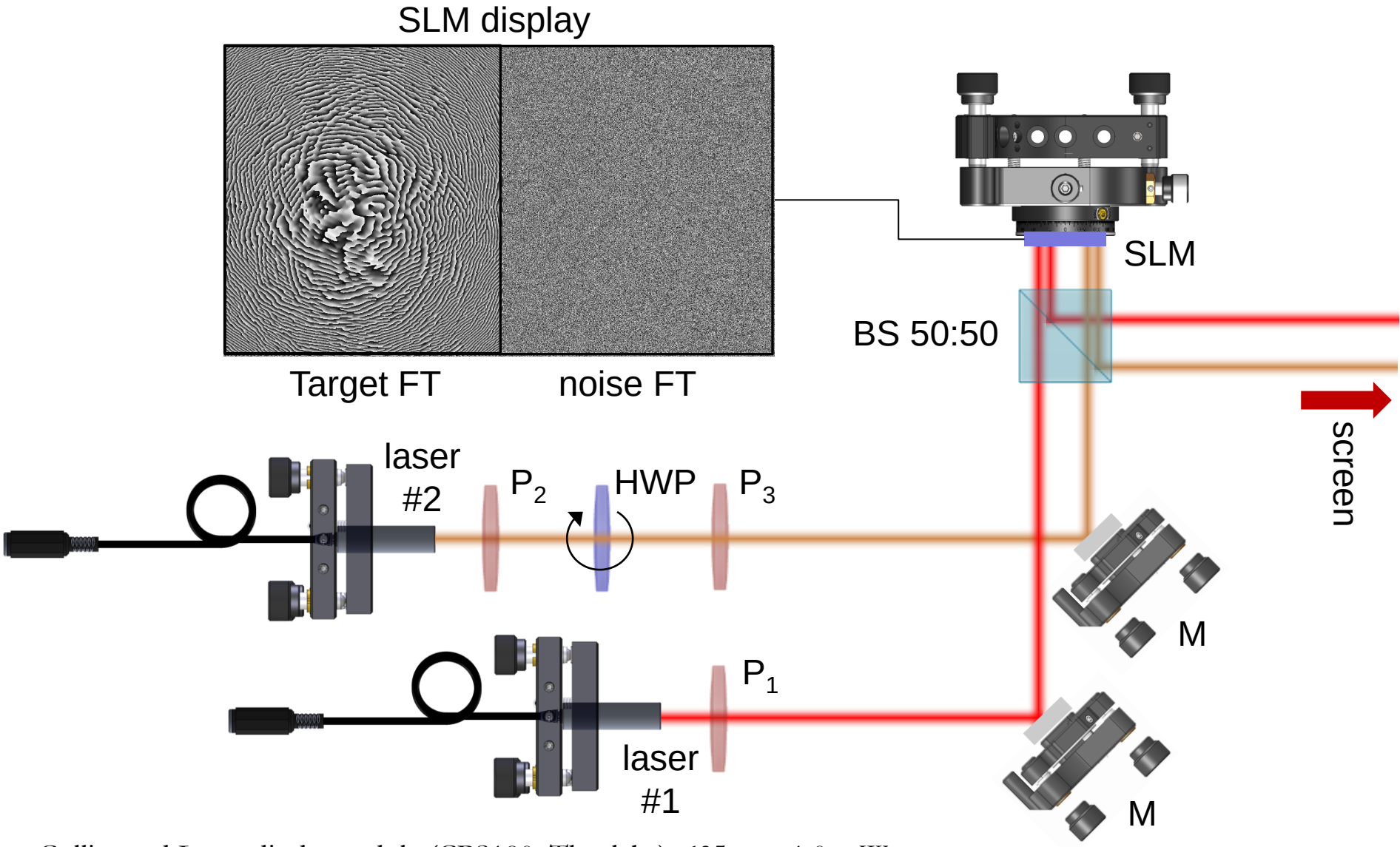


D. V. Dylov, *et al. EEE J. Sel. Top. Quantum Electron.* **18** (2011)



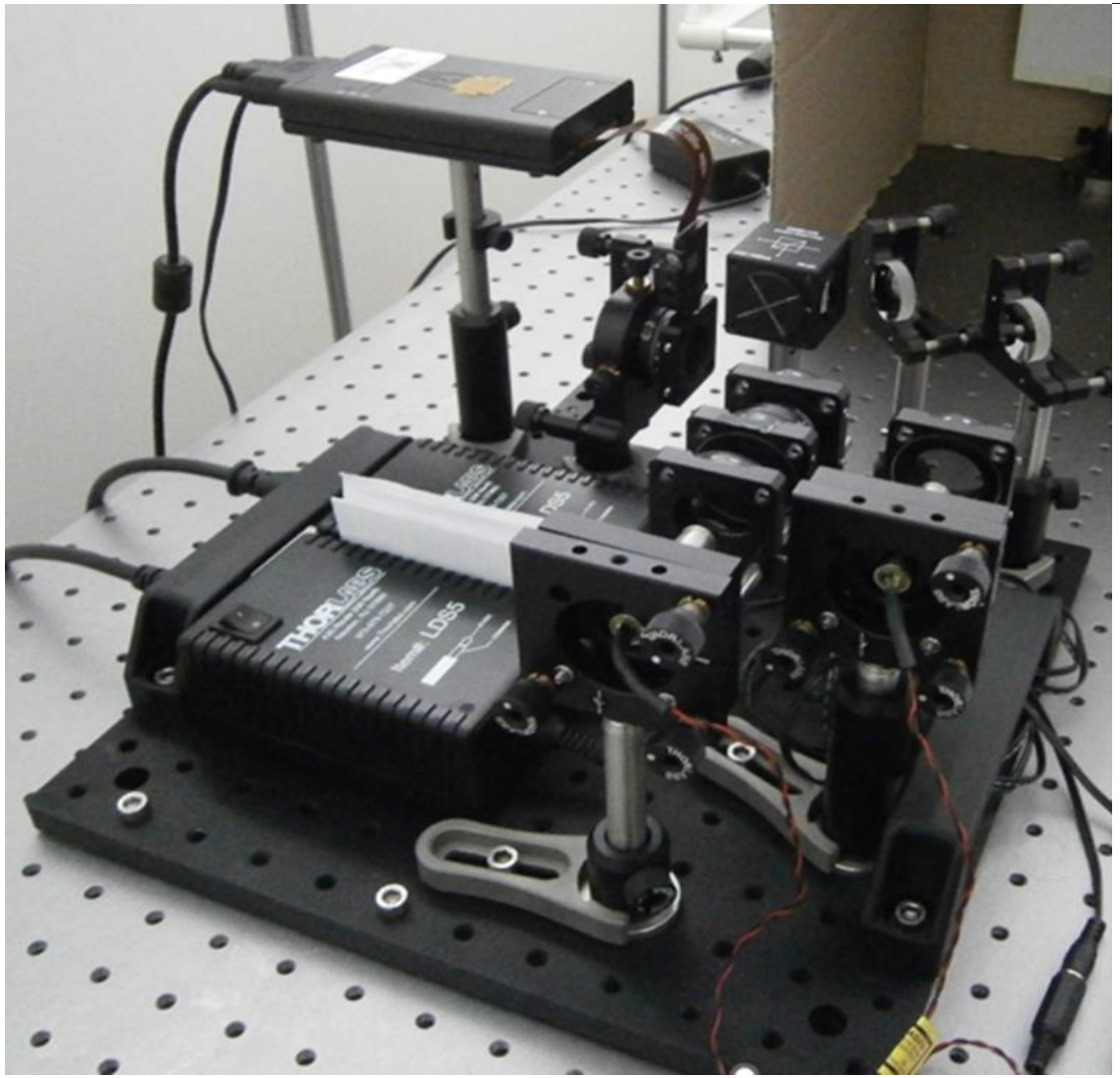
E. Simonotto, *et al. Phys. Rev. Lett.* **78**, 1186 (1997)

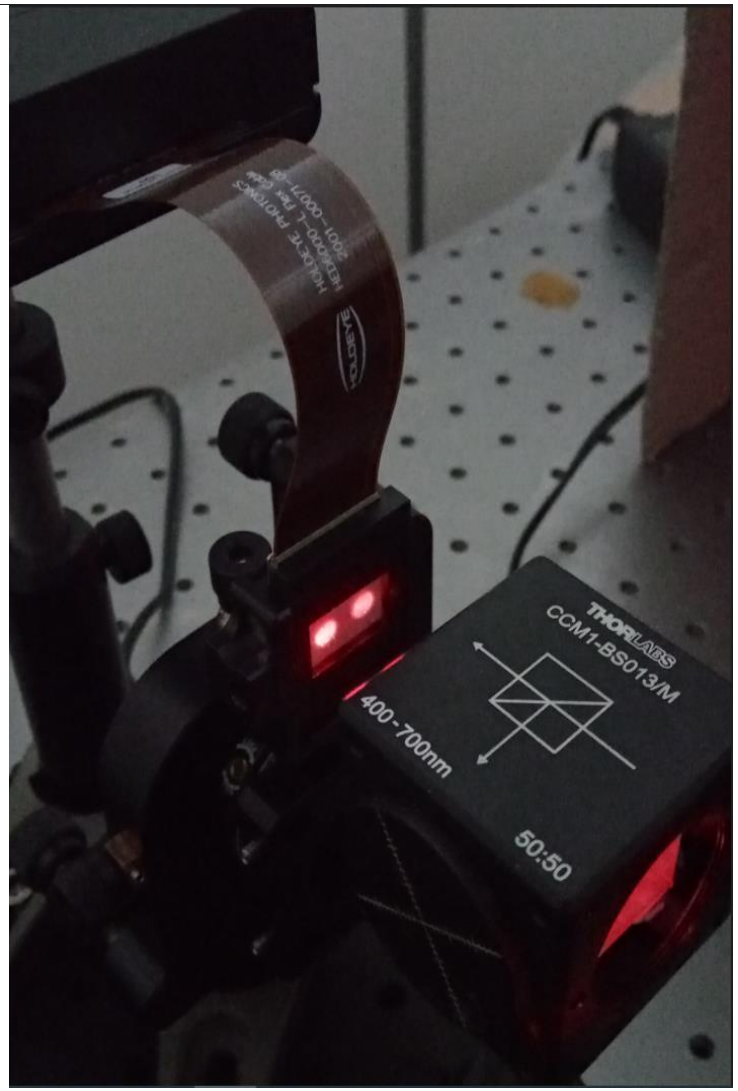
Adding noise to the setup



Collimated Laser diode module (CPS180, Thorlabs): 635 nm, 1.0 mW

Adding noise to the setup





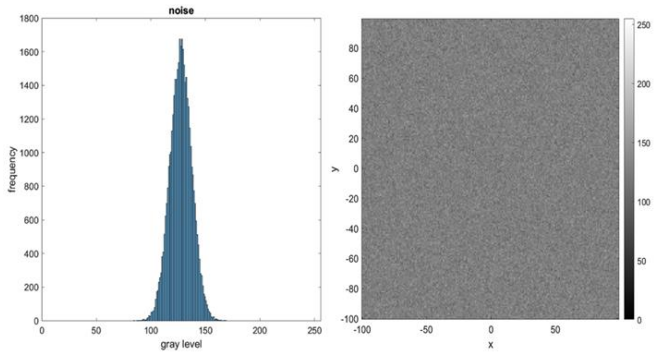
Preliminary tests on CS + noise

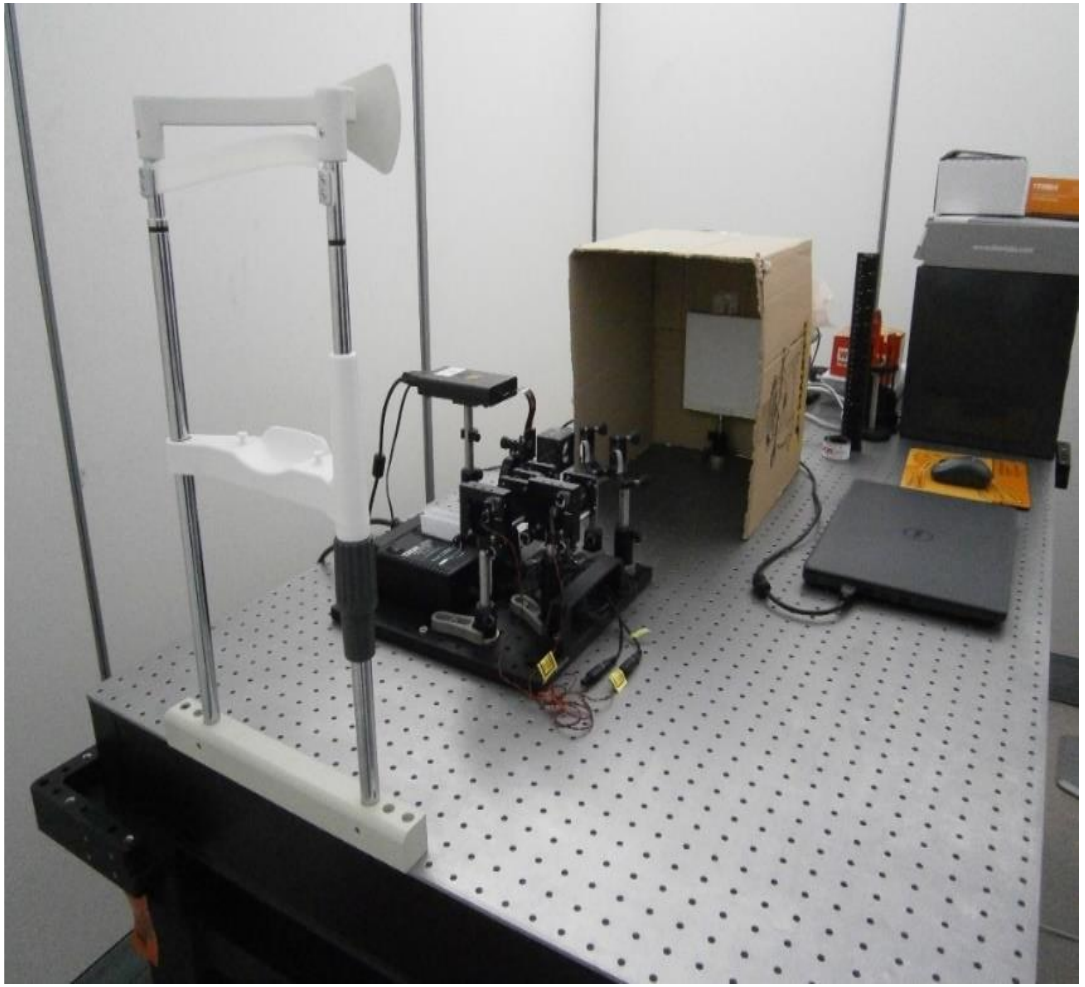
Psychophysical tests have been performed on a group of 12 people (7 W, 5 M), age 27.6 ± 5.4.

Distance: 1 m
Binocular test wearing usual correction

Test procedure:

1. CS test to identify the threshold (x3)
2. Tests with noise (15 trials):
   - 6 levels of noise σ
   - 10 levels of noise intensity

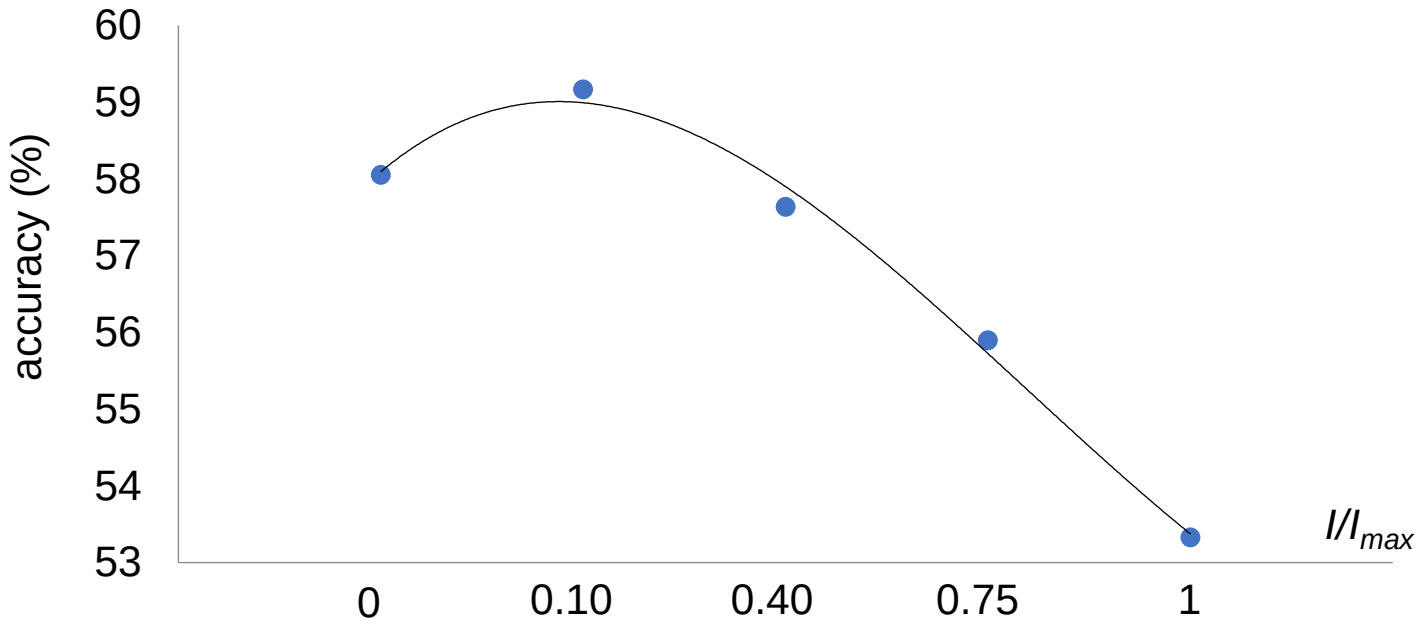




Total time: 2 h 15 min

Preliminary results – effect of noise

- Noise RMS is not significant
- Noise total intensity is significant and affects the test performance

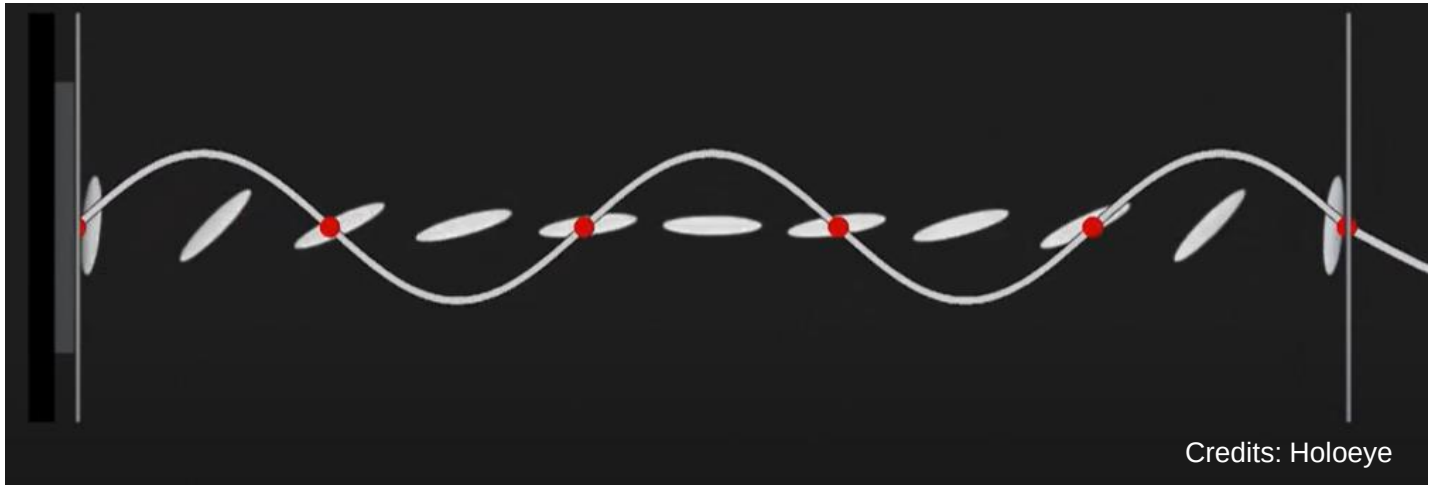


The difference in accuracy (% of correct answers) is significant (p-value<0.05). However, the improvement is quite low. Further investigations are required (wider sample, optimize the test)

Conclusions and perspectives

- We have assembled a new setup never used in literature based on spatial light modulators and tested in its effectiveness to perform both optometric and psychophysical tests
- Validated the programming of visual acuity and contrast sensitivity tests
- First prototype of a series of portable, compact, and versatile optometric devices for the realization of a rich variety of programmable tests
- All the optical elements and sources can be integrated and miniaturized into a compact architecture
- Demonstration that noise tangibly and measurably affects visual perception although further investigation on a larger scale is needed to validate the data in relation to stochastic resonance
- Advantages: dynamic, portable, and versatile

Thanks for your kind attention!



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