



# HORUS

## Final Presentation

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11.12.2018



# About the project



How we described it in the proposal



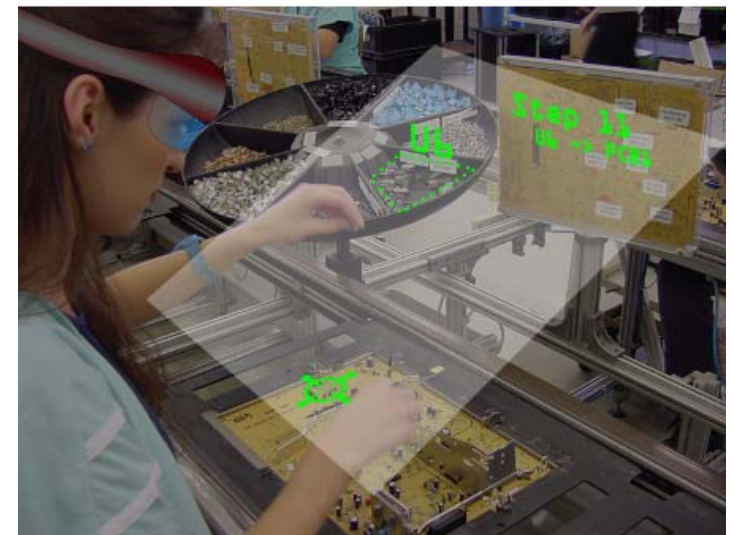
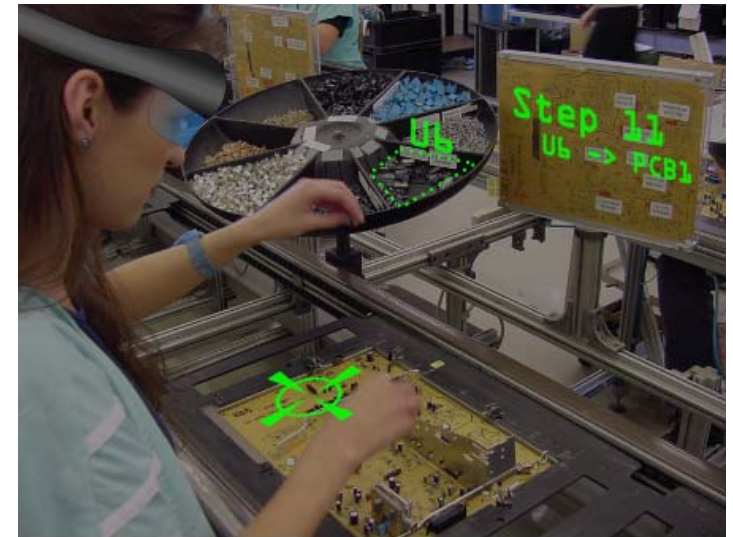
How ESA understood it



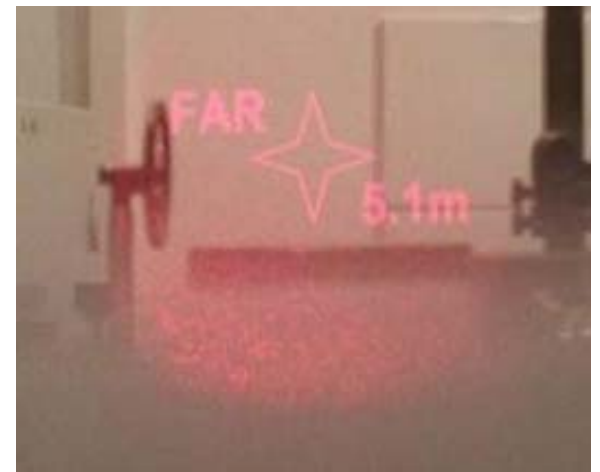
What we delivered

# Project goals

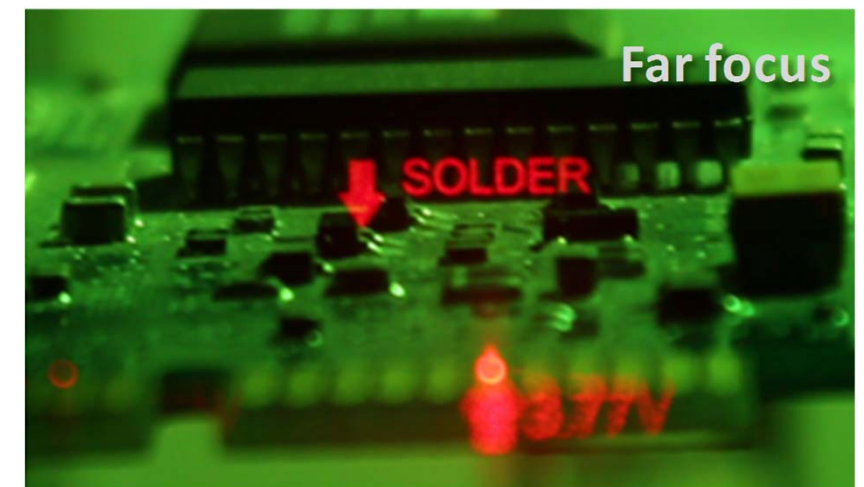
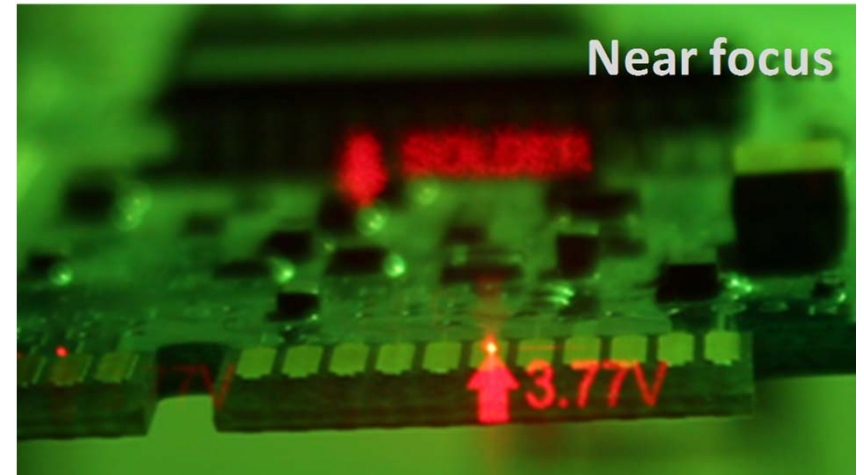
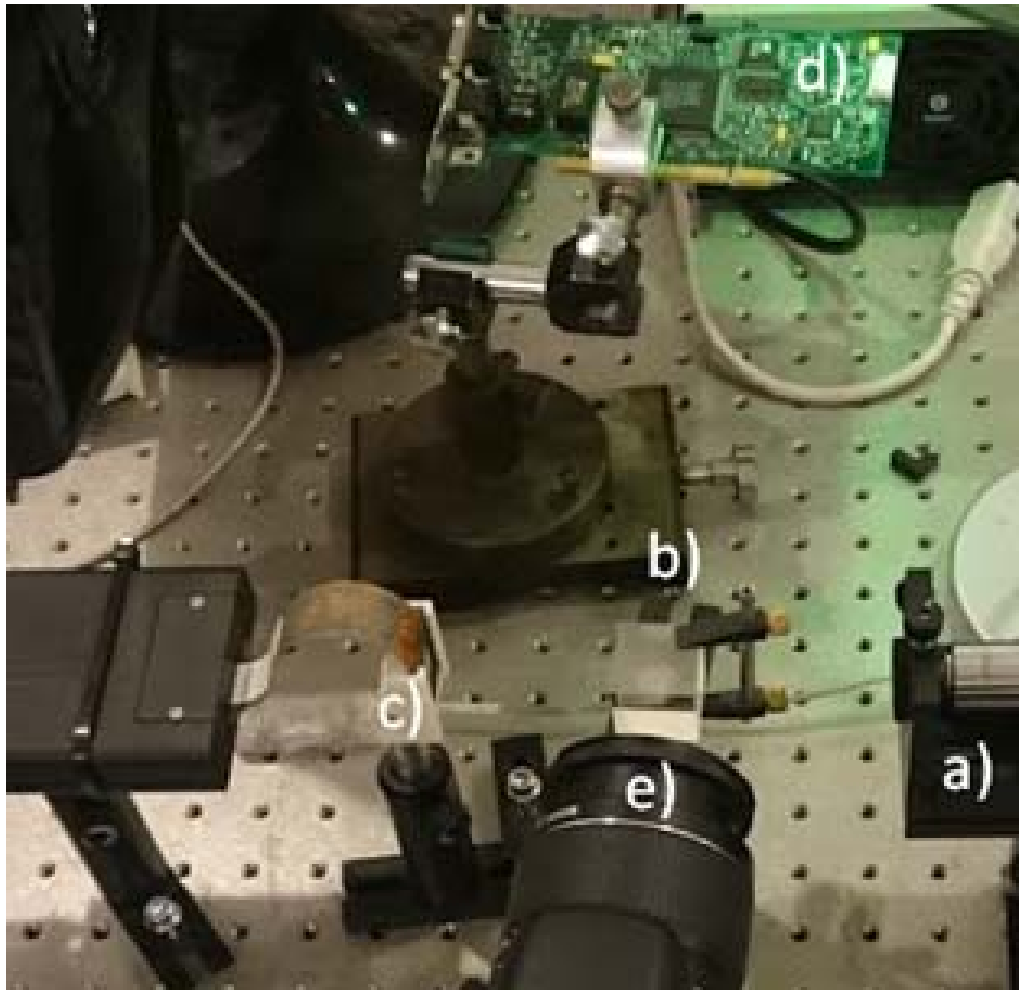
- Novel type of translucent head mounted display
  - free of drawbacks of currently available devices
- Application: contextual assembly support for space industry
- TRL 3 → 5
  - demonstration of critical functionality in relevant environment



- True holographic display
  - Multiple and dynamic focal distances
  - 3D effect with single eye
  - No ambient light related limits
  - Reduced sight fatigue
- Same AR/MR principles

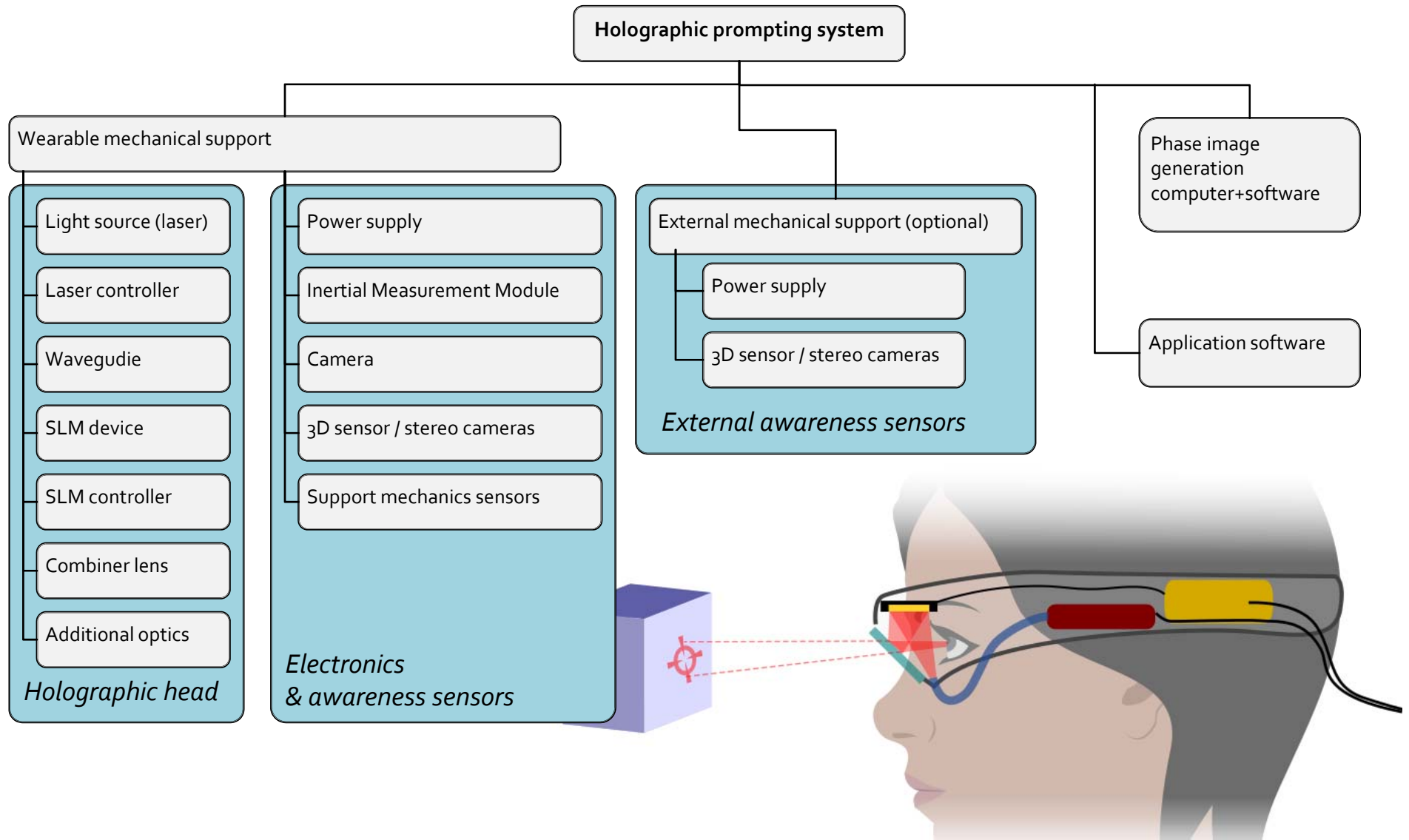


# Starting point

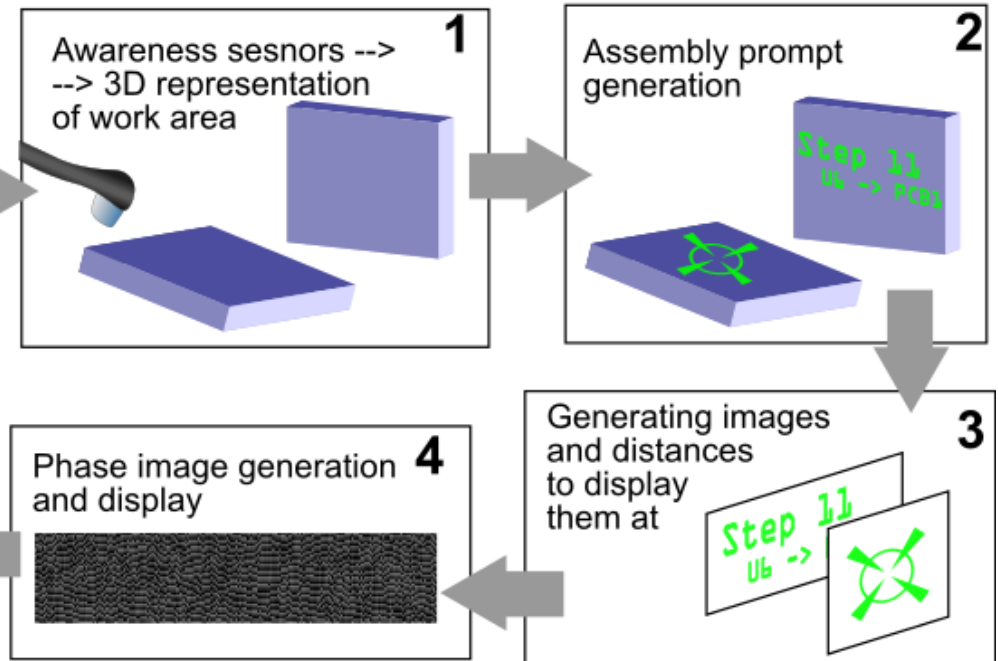
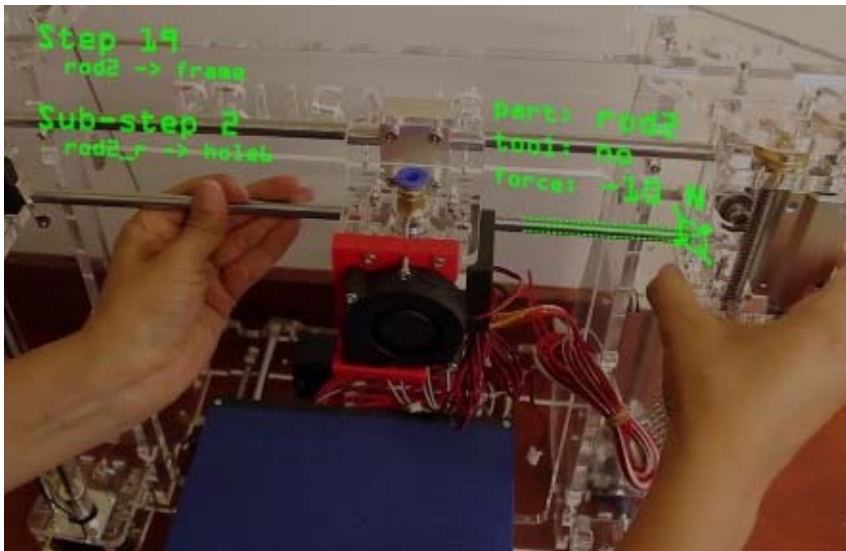
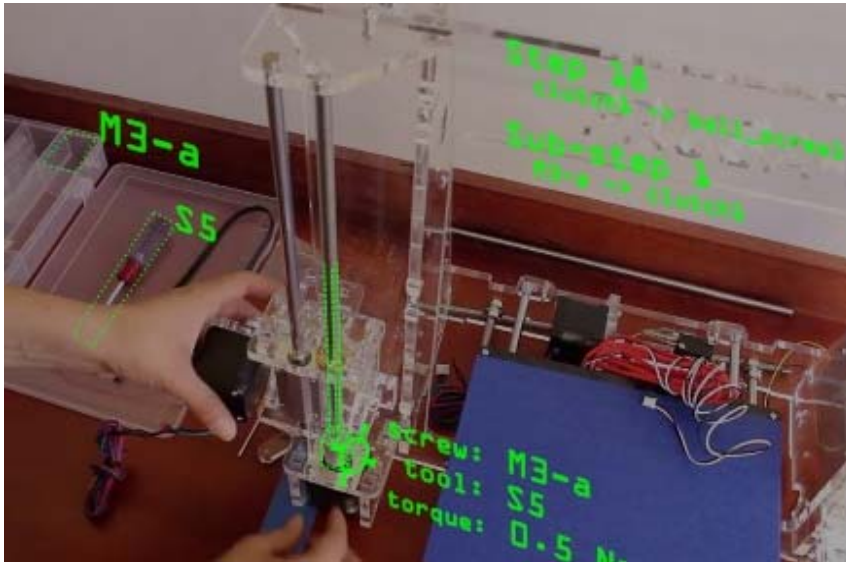


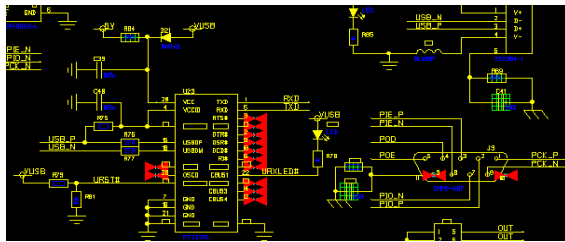


# Main system components



# Application





## Wydział Fizyki

POLITECHNIKA WARSZAWSKA

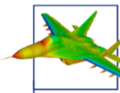


## CIM-mes projekt

Design

Technology

Prototyping



Complex  
Aerodynamics



External CFD  
Simulations



Shape  
Optimisation



Crash  
Automotive



Crash  
Shipbuilding



Welding  
deformations



Stamping  
simulations

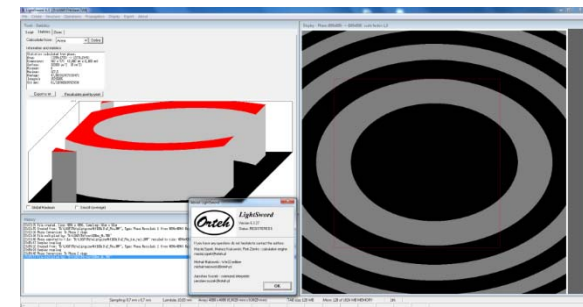


Prototypes  
short series



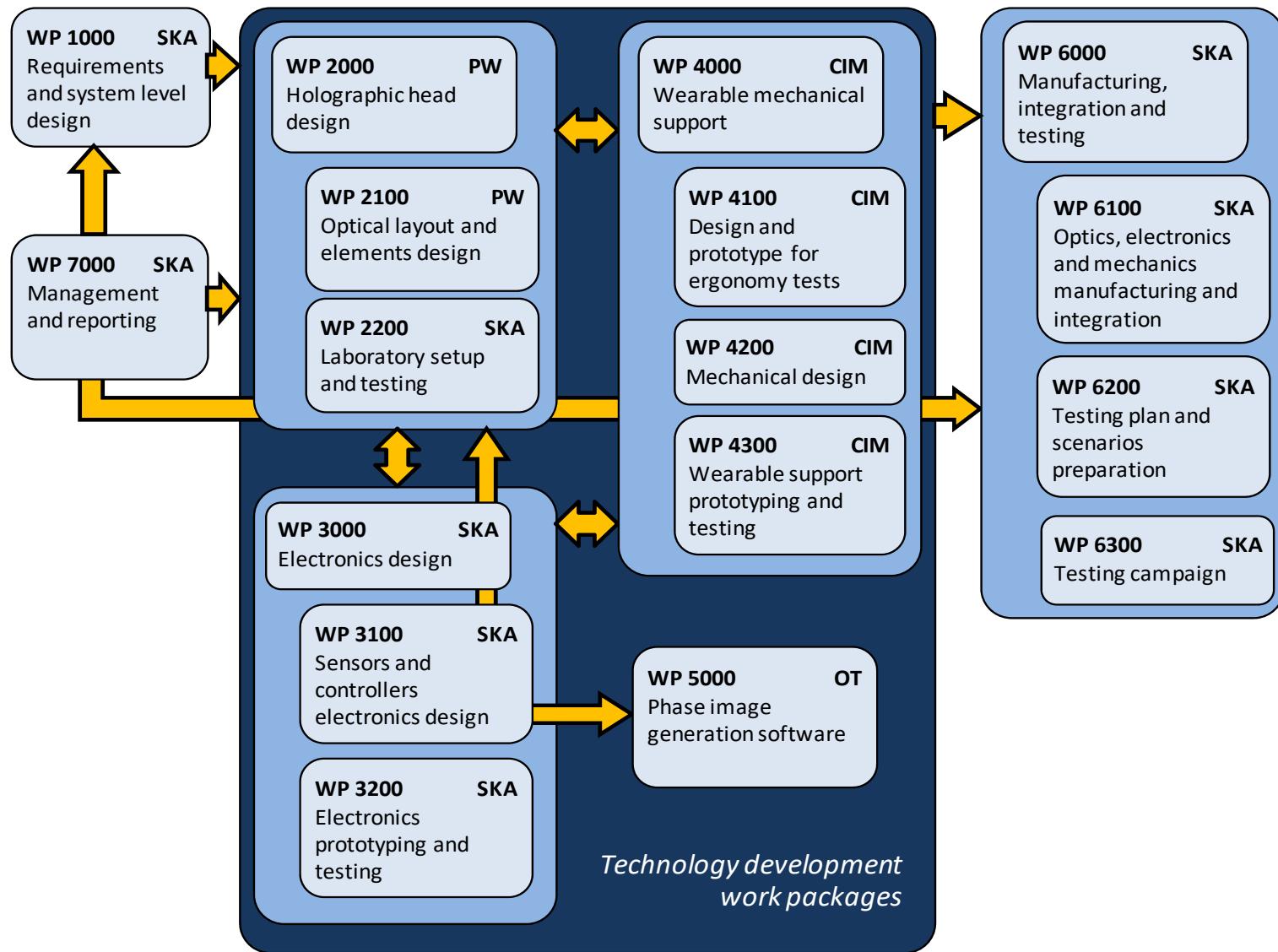
Custom eng.  
software

# Ortech



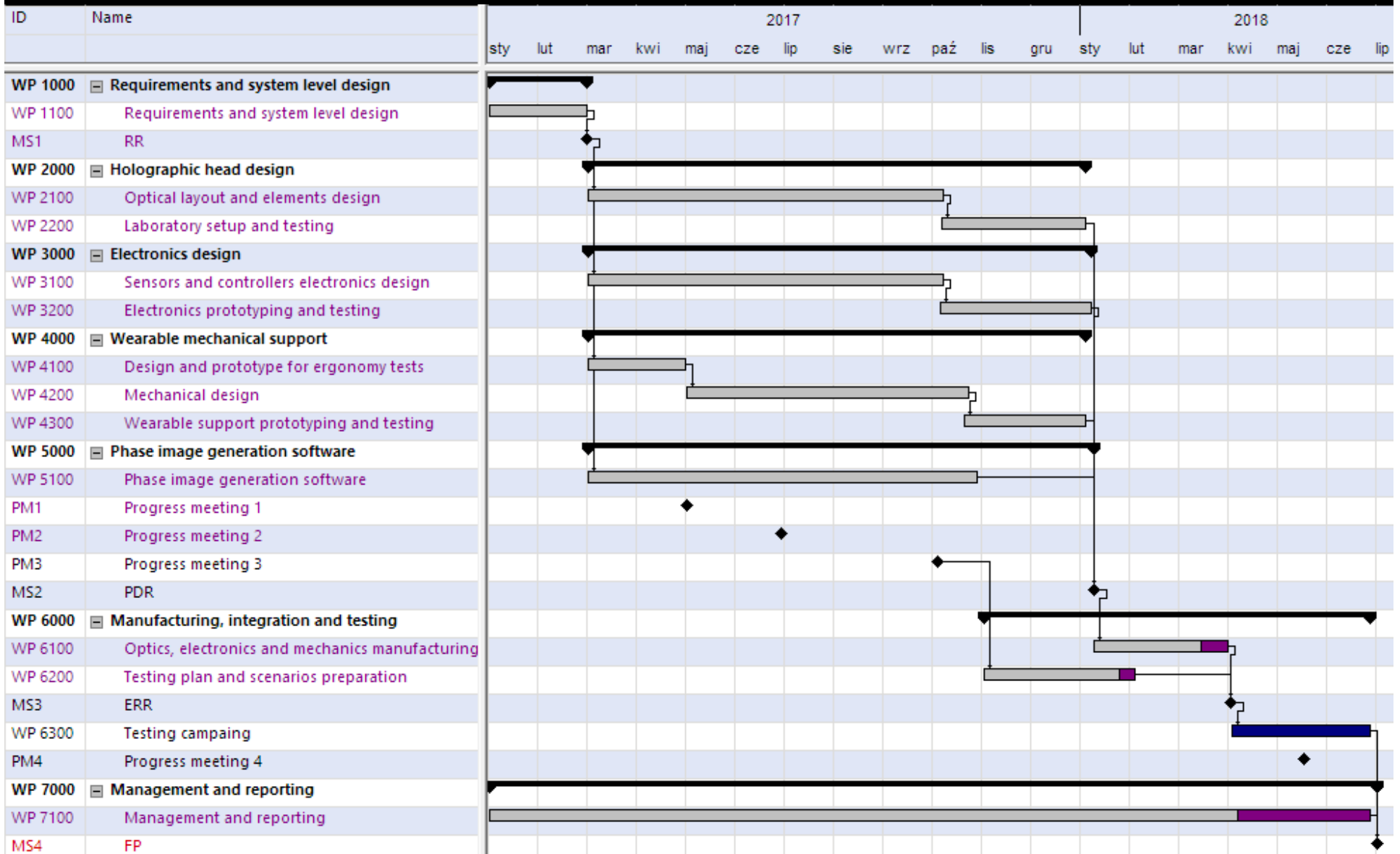


# Work structure





# Project schedule

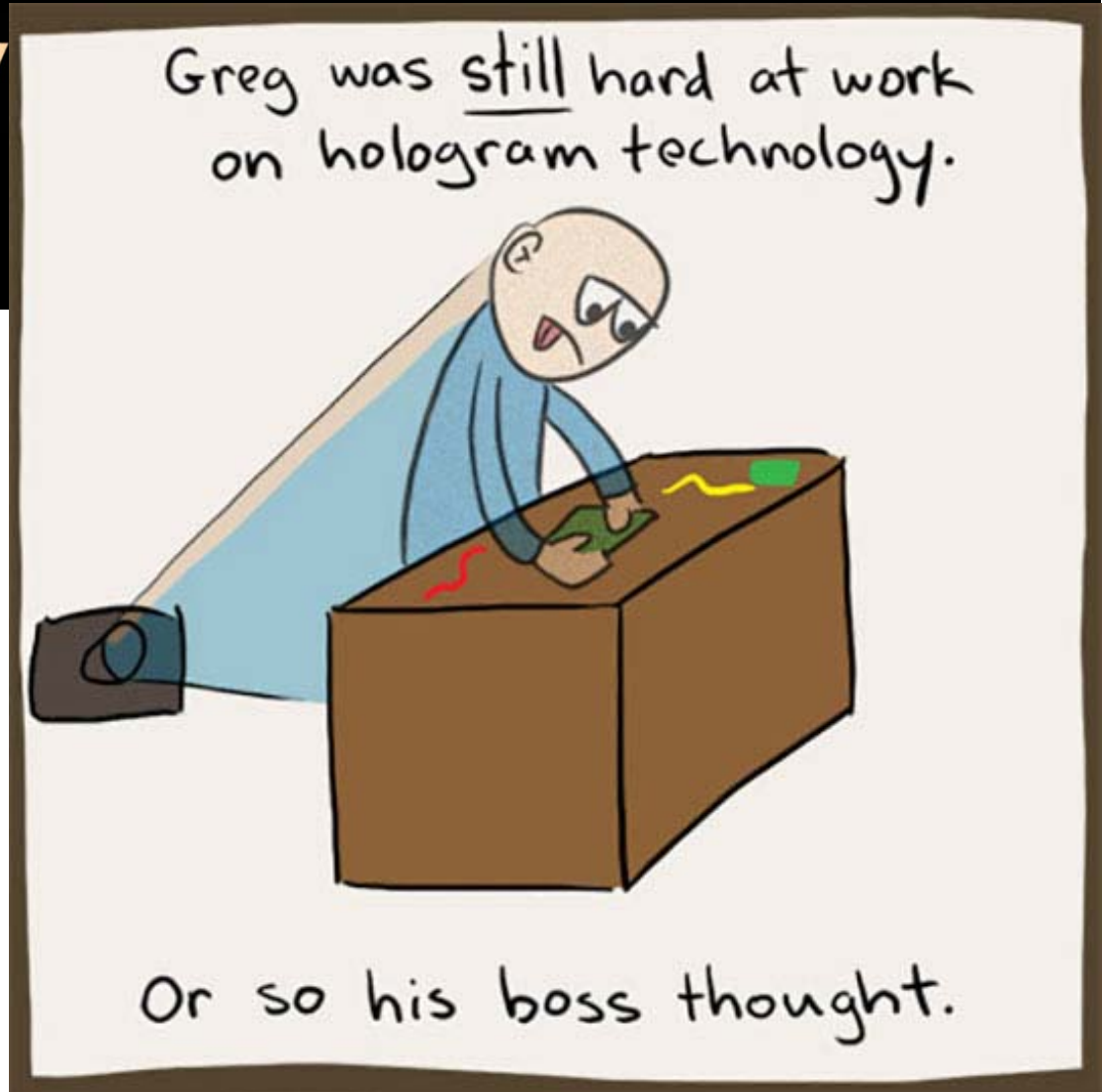




# Deliverables

Description	ID	Title	Delivery date	Milestone
Document	TN1	Requirements and system level design	To+2	RR
Document	TN2	Optical layout design and performance report	To+10	PDR
Document	TN3	Electronics modules design and performance report	To+10	PDR
Document	TN4	Mechanical support design and performance report	To+10	PDR
Document	TN5	Phase image generation software documentation and performance report	To+10	PDR
Document	TN6	Testing plan and scenarios	To+13	ERR
Document	TN7	Wearable holographic prompt test report	To+18	FP
Document (design files)	CD1	Optical layout CAD files and BOM (updated)	To+6 To+10 (updated)	PDR
Document (design files)	CD2	Electronics modules schematics, PCB layouts and BOM	To+6 To+10 (updated)	PDR
Document (design files)	CD3	Wearable support CAD files and BOM	To+6 To+10 (updated)	PDR
Software (binary)	SW1	API for awareness sensors data acquisition	To+10	PDR
Software (binary)	SW2	Phase image generation software	To+10	PDR
Hardware	HW1	Wearable support mock-up Ergonomics tests conclusions	To+4	
Hardware	HW2	Wearable holographic prompt prototype	To+13	ERR
Technical Data Package	TDP		To+18	FP
Final Report	FR		To+18	FP
Executive Summary Report	ESR		To+18	FP

# Holography



# What is holography?

- Probably most popular image of holography  
(Thank you George Lucas)



# What is holography

- What IS holography?





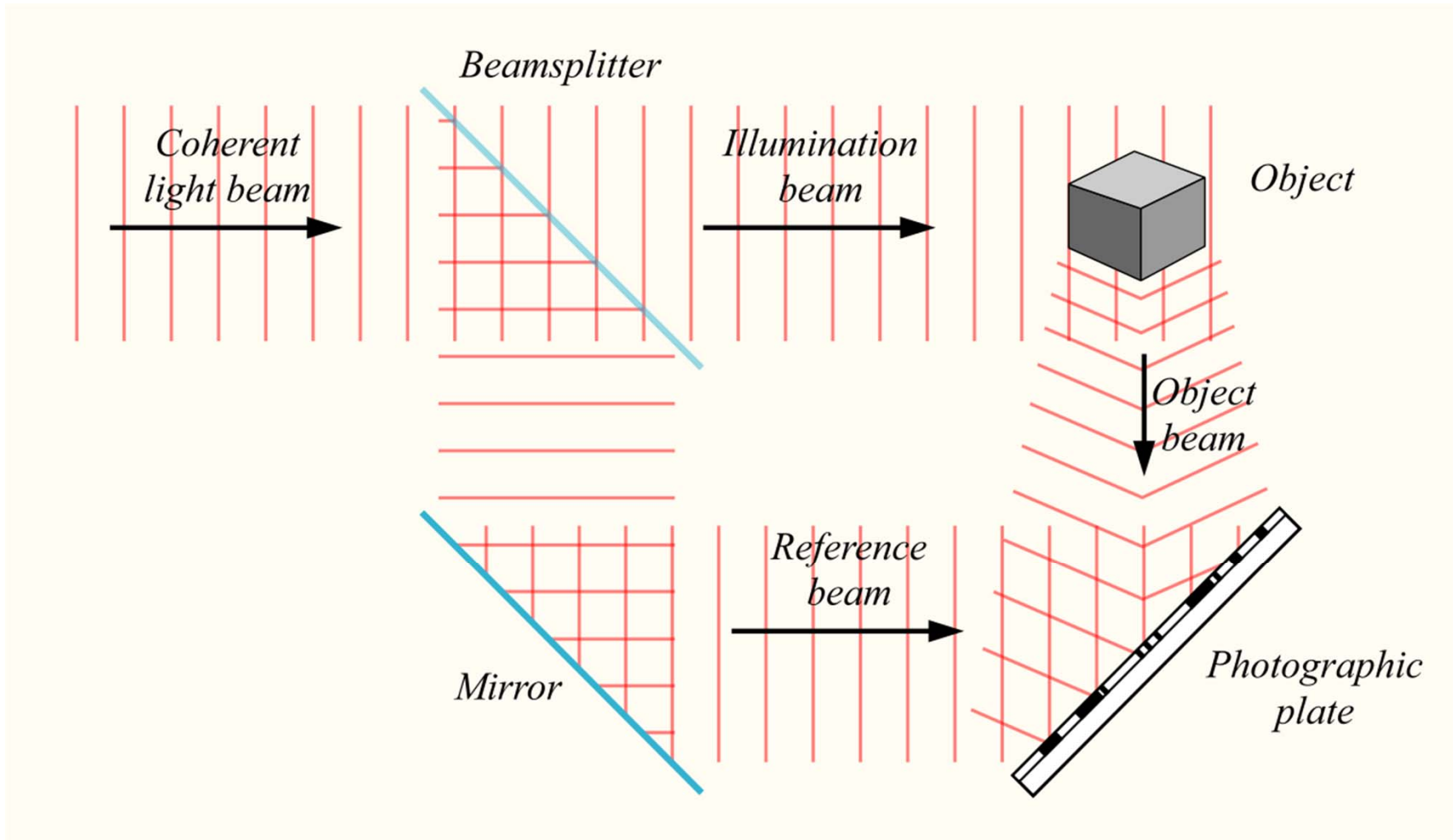
# What is holography?

- Classic holography is visually perfect, but static.





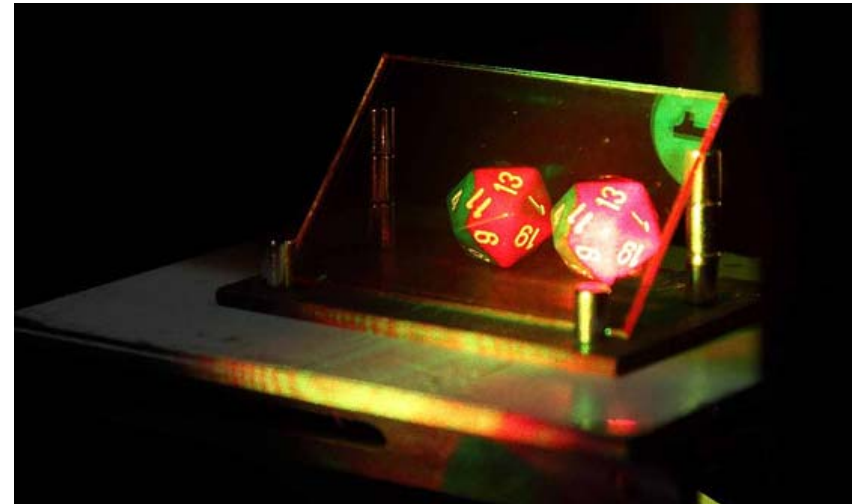
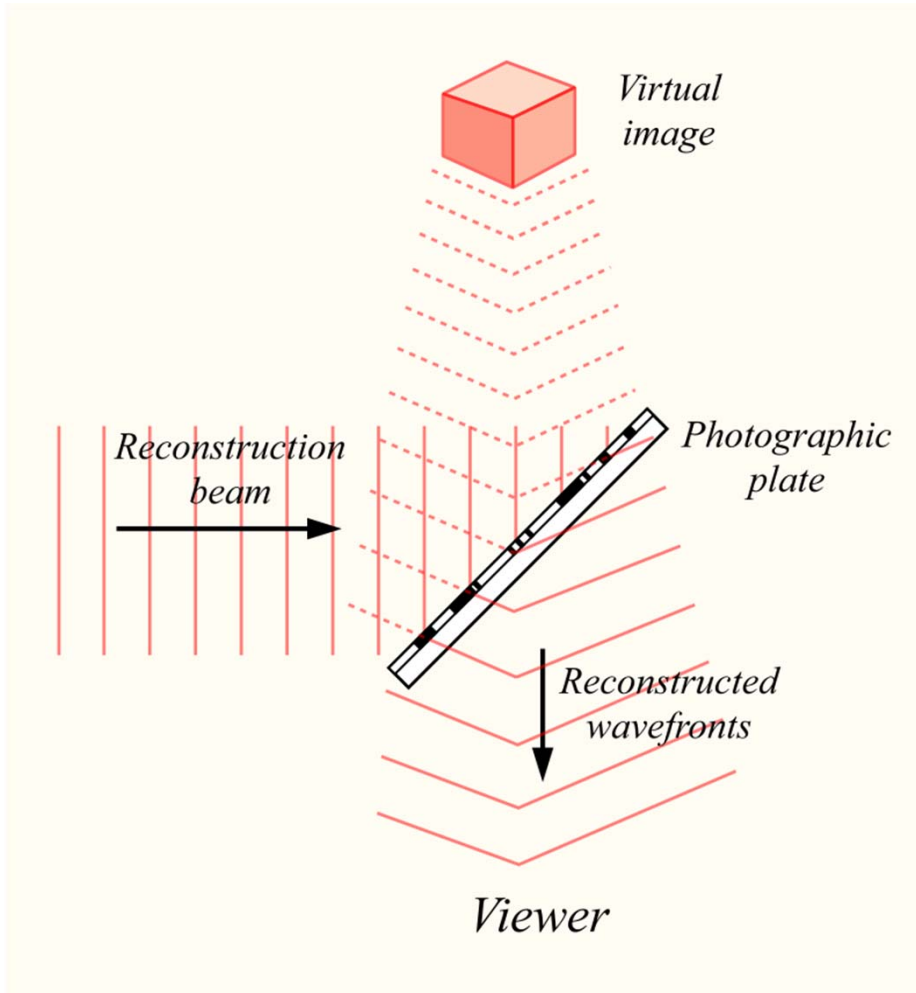
# How holography works?







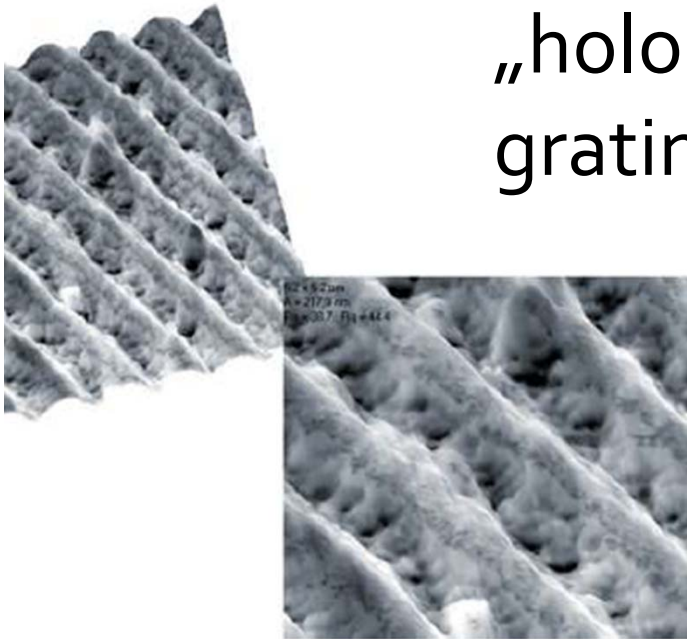
# How holography works?



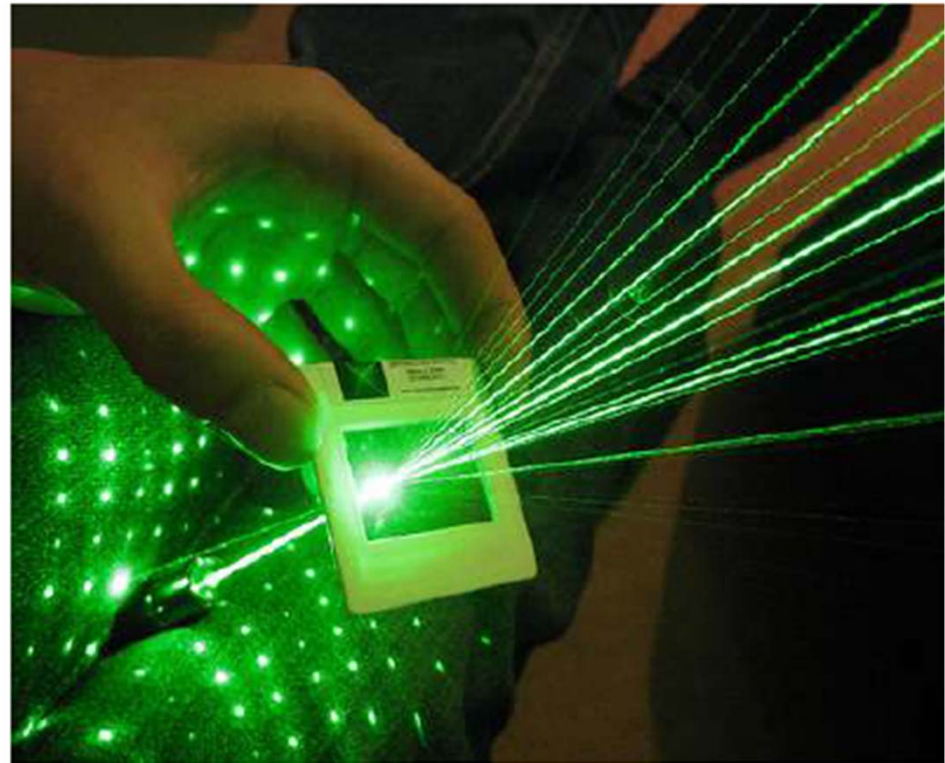


# Hologram is a complicated grating

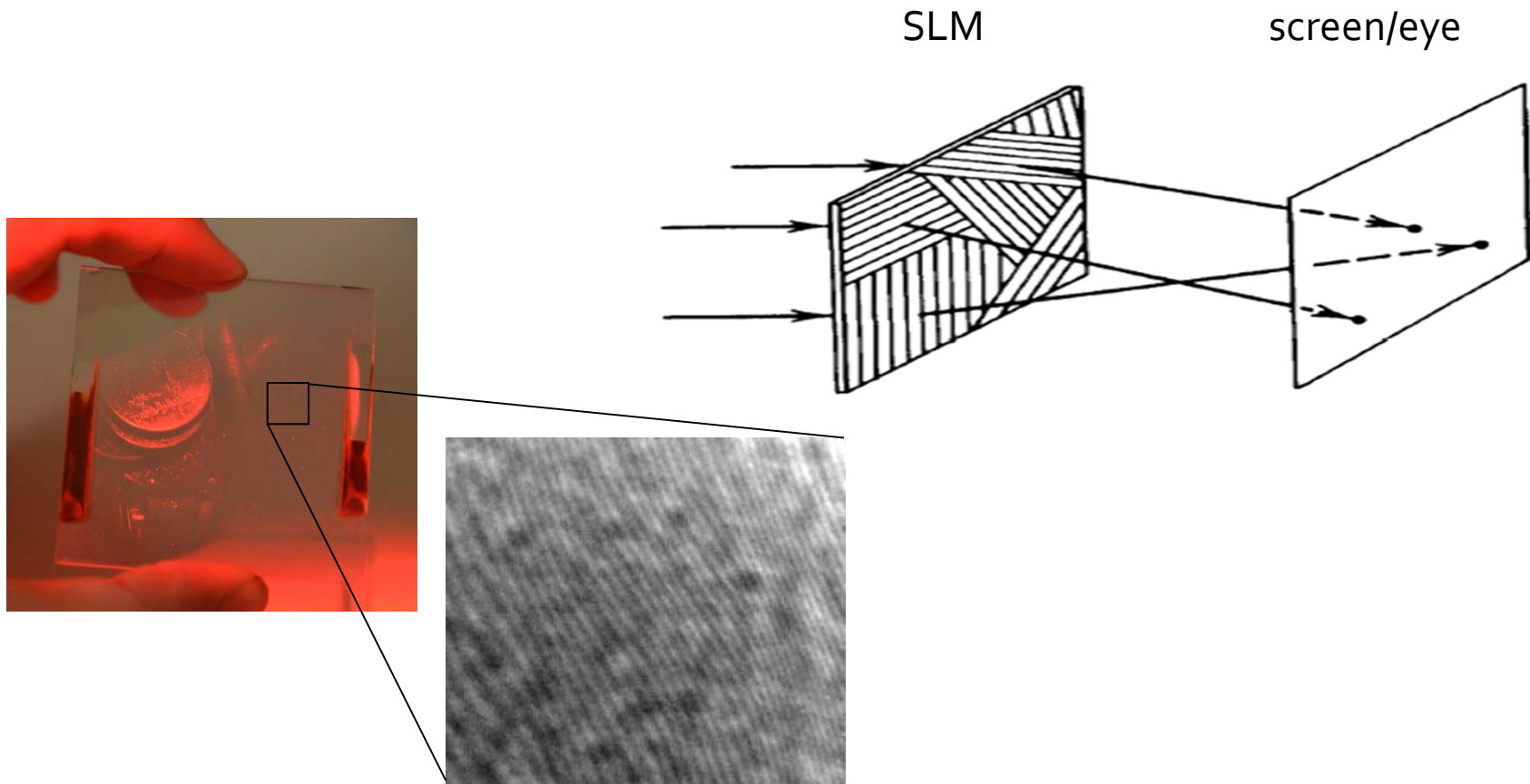
- We can imagine that the simplest „hologram“ is diffractive phase grating



Hologram



- How does holography display images?





# CGH – what is needed?

To calculate CGH we need :

- Amplitude – „amount“ of light
- Phase – „direction“ of light

Human eye is sensitive for intensity =  $|\text{Amplitude}|^2$



# Computer Generated Hologram

- In ideal situation one can code hologram image as amplitude and phase of light



Input image

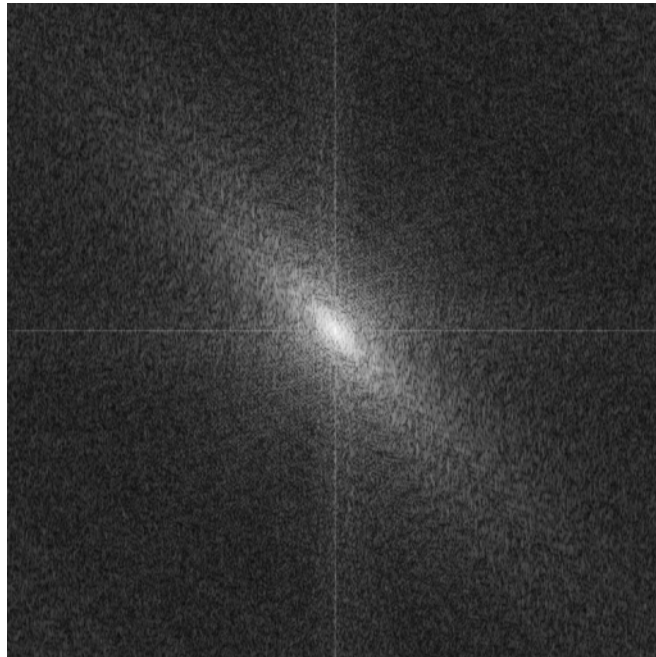


Reconstruction

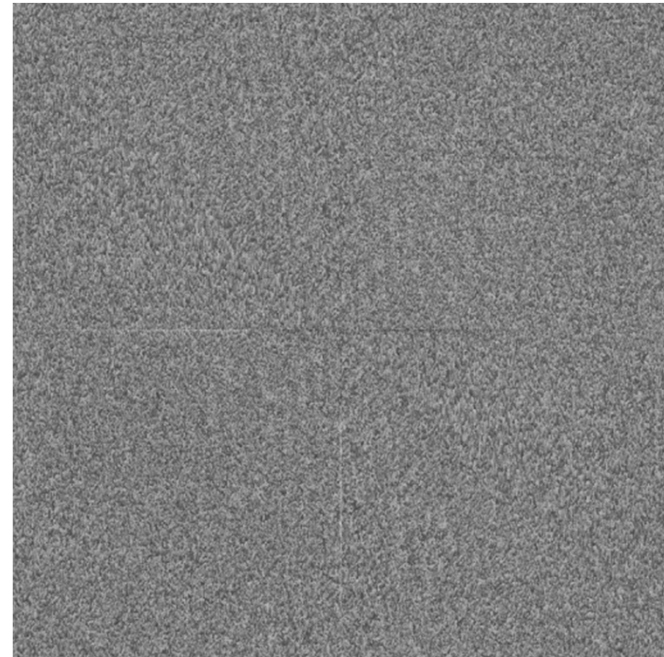


# Computer Generated Hologram

- In real situation usually we can't keep both: amplitude and phase



Amplitude distribution



Phase distribution



# Computer Generated Hologram

- Reconstruction from phase only



Input image



Reconstruction



# Computer Generated Hologram

- Reconstruction from phase only with diffusor



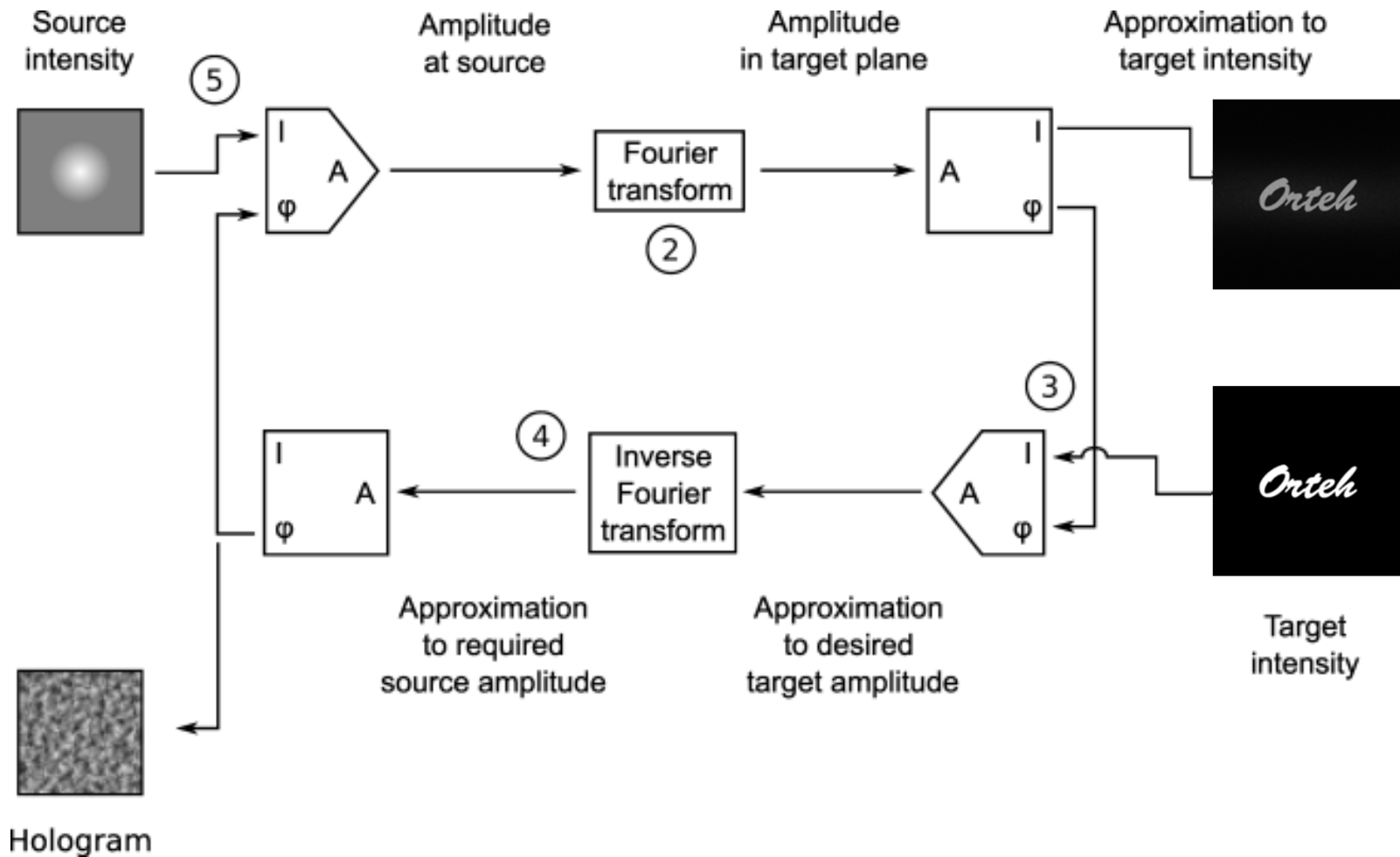
Input image



Reconstruction

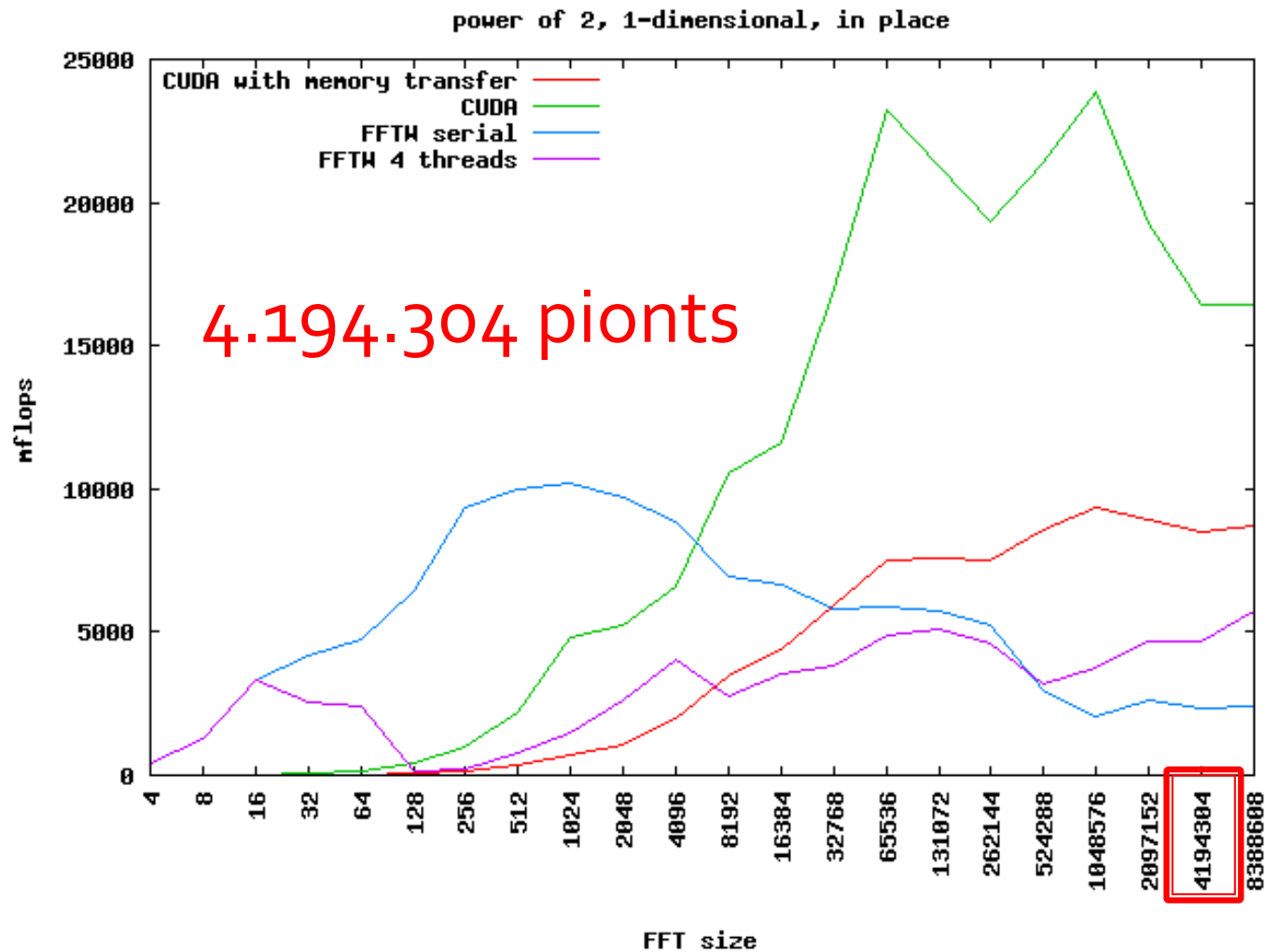


# Algorithm - IFTA





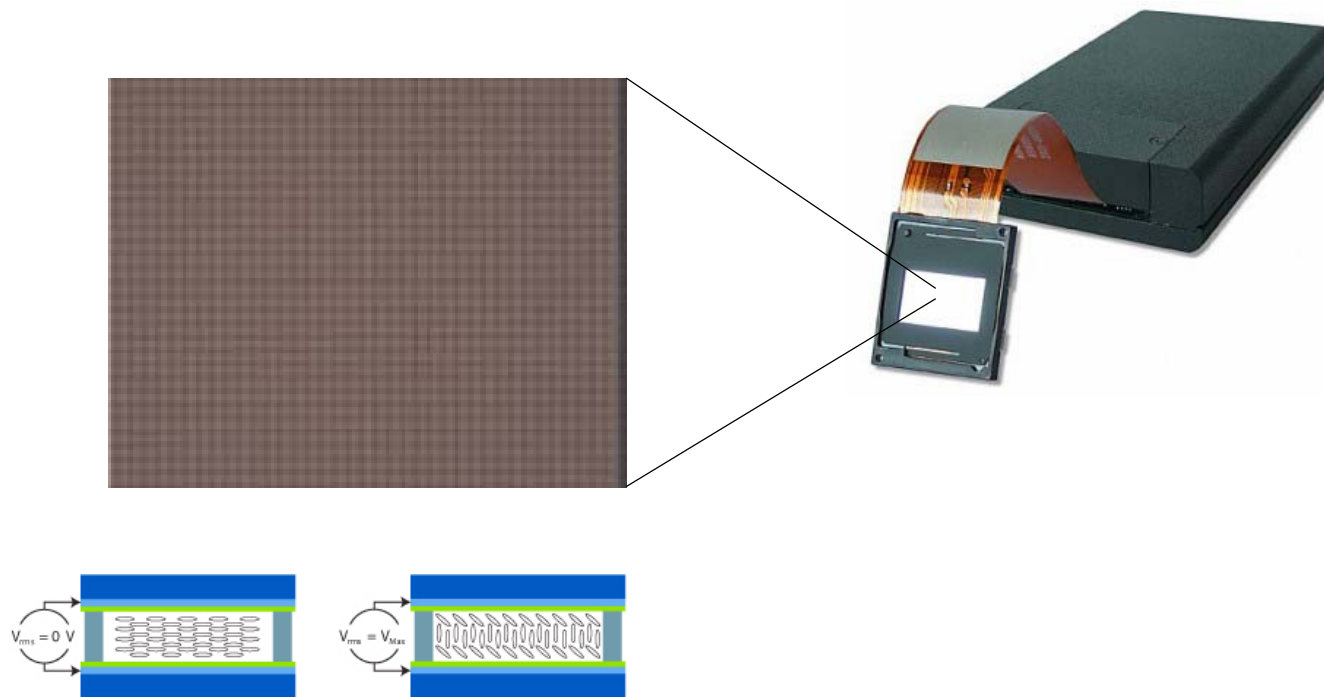
# Computational complexity





# How SLM works?

- SLM alters the phase (delay) of light beams

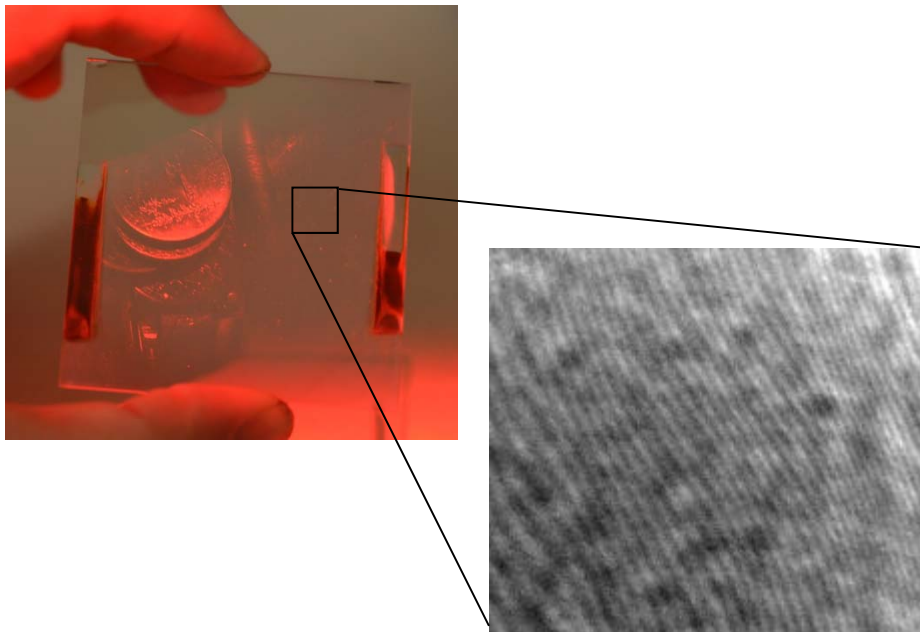


Electronically controlled birefringence – change of the refractive index per pixel

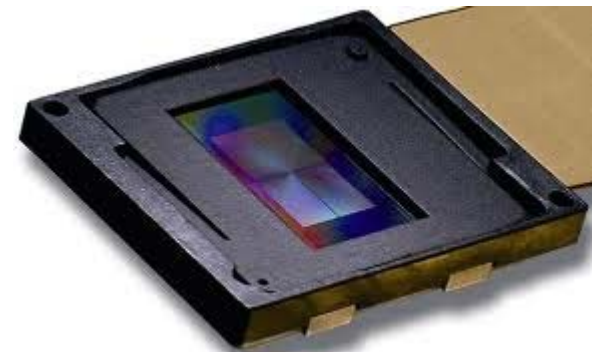
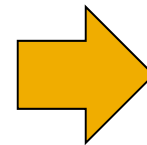


# How SLM works?

- Computer Holography on Spatial Light Modulators allow animated 3-D images

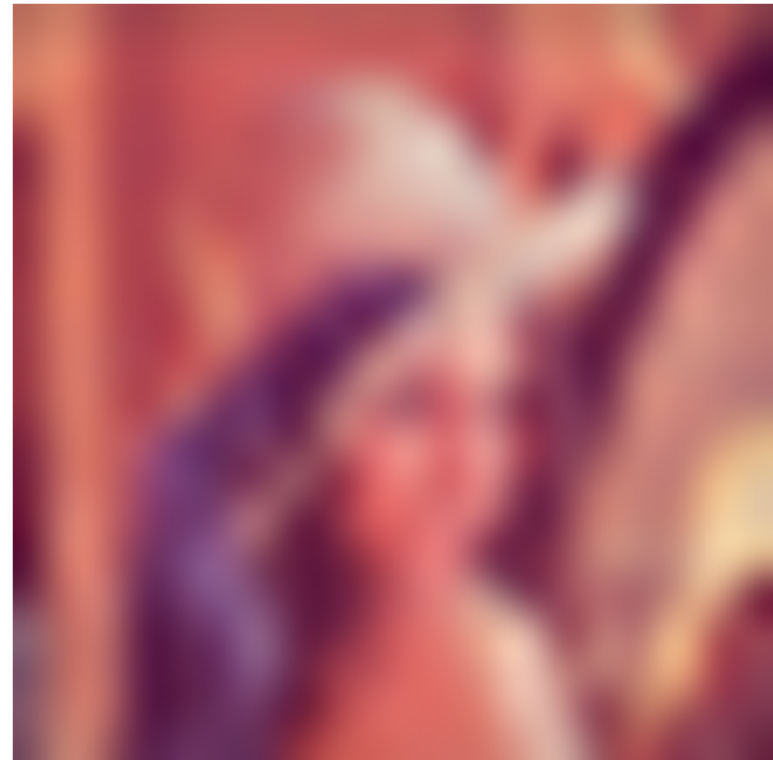


Typical classic hologram:  
10 „Gpx“, 3000 lp/mm, static image only



Spatial Light Modulator, SLM  
4k x 2k (8 Mpx) pixels, 125 lp/mm  
60 frames/s – animated images

# SLM resolution



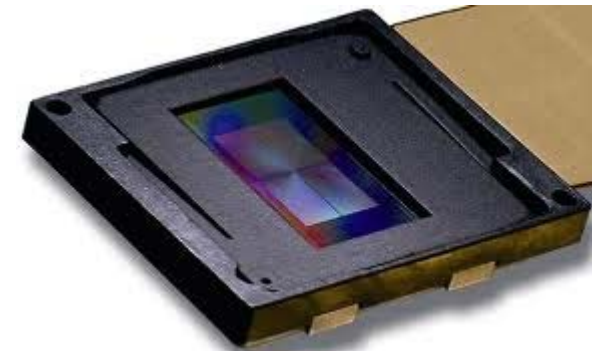
# How SLM limitations

## 2.1 Display parameter

Part no.	HED 7010 xxx
Type:	LCOS (reflective), Active Matrix LCD
Drive scheme:	Digital (pulse code modulation)
Mode:	PAN (Parallel Aligned Nematic)
Phase levels:	256 (8-bit) levels
Active Area:	15.32 mm x 9.22 mm
Resolution Nominal:	4094 x 2464 pixels (3840 x 2160 pixels)
Pixel Pitch:	3.74 $\mu\text{m}$
Fill Factor:	90 %
Image Frame Rate:	24 Hz (4094 x 2464 Pixel) 30 Hz (3840 x 2160 Pixel)
Reflectivity $f(\lambda)$ :	62% - 72%
Illumination (max.):	$\sim 2 \text{ W} / \text{cm}^2$ For high power and pulsed laser applications please contact HOLOEYE.
Operating temp.:	+10 °C to +70 °C
Waveband:	Model dependent.



Figure 3: 4K phase display



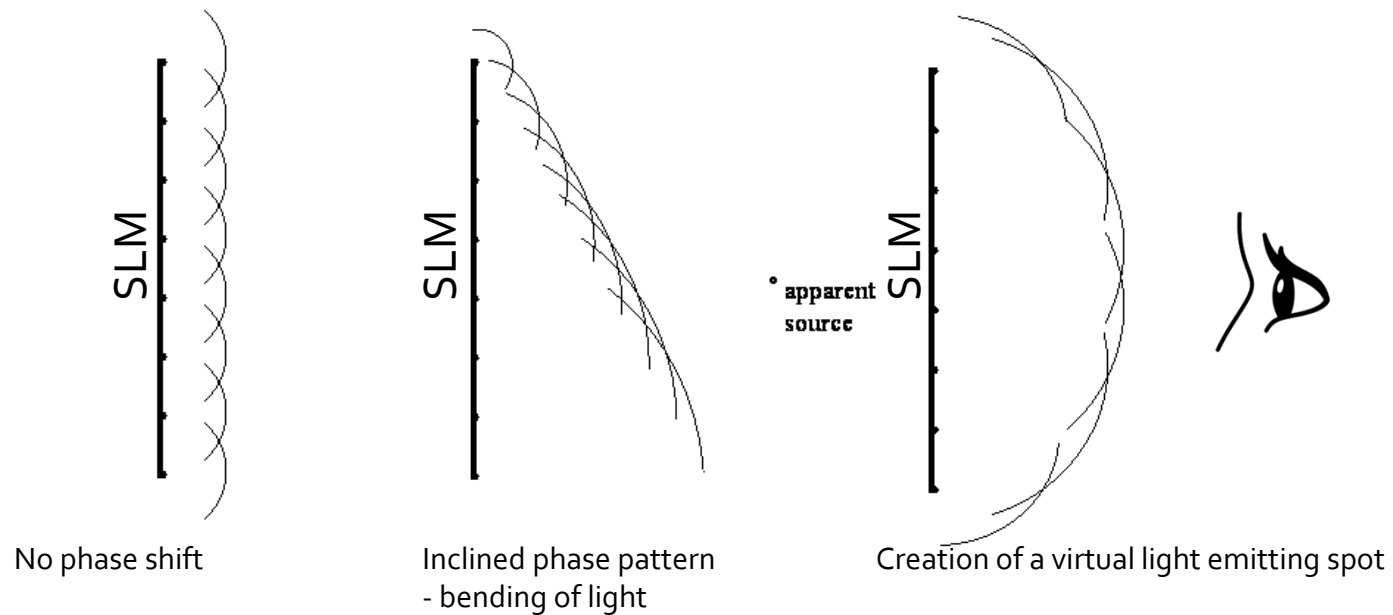
Spatial Light Modulator, SLM  
4k x 2k (8 Mpx) pixels, 125 lp/mm  
60 frames/s – animated images



UV irradiation below 405 nm shall be blocked via an absorption filter

# SLM and holography

- How does holography display images?

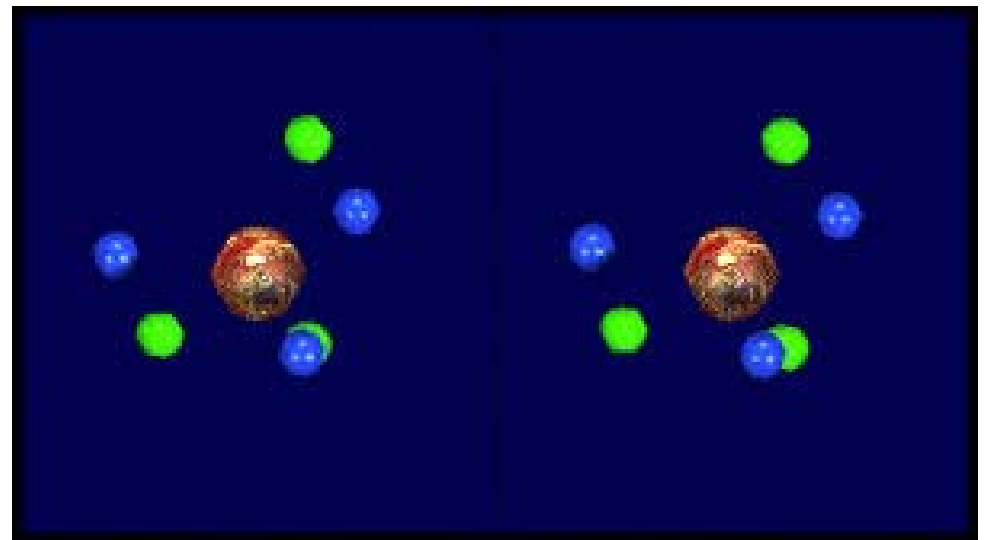




- But there is NO holography at all  
(sorry Microsoft, but that is true)



# Stereography



# Stereography is pretty old

- 1899 – still working in Warsaw 😊



# Stereography is pretty old



The only significant difference is the way the image is displayed  
After more than 100 years we replaced paper with LCD display

# Disadvantages of stereography

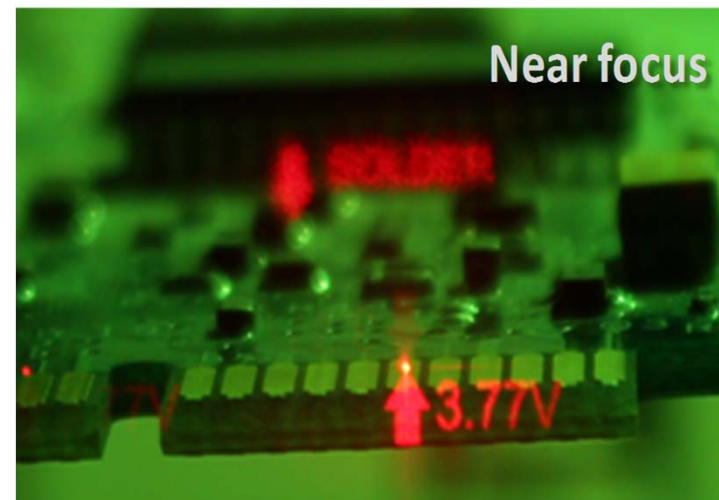
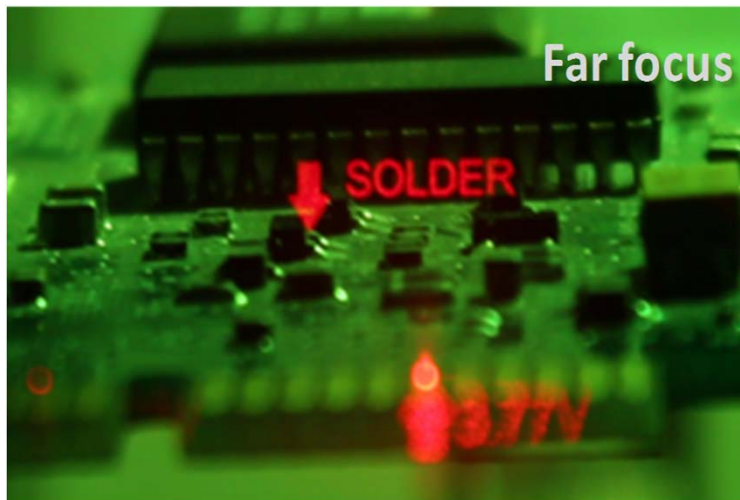
- It's not 3D – tiring sight and center of balance
- Intensity image only – low efficiency
- One fixed plane of image (usually far)





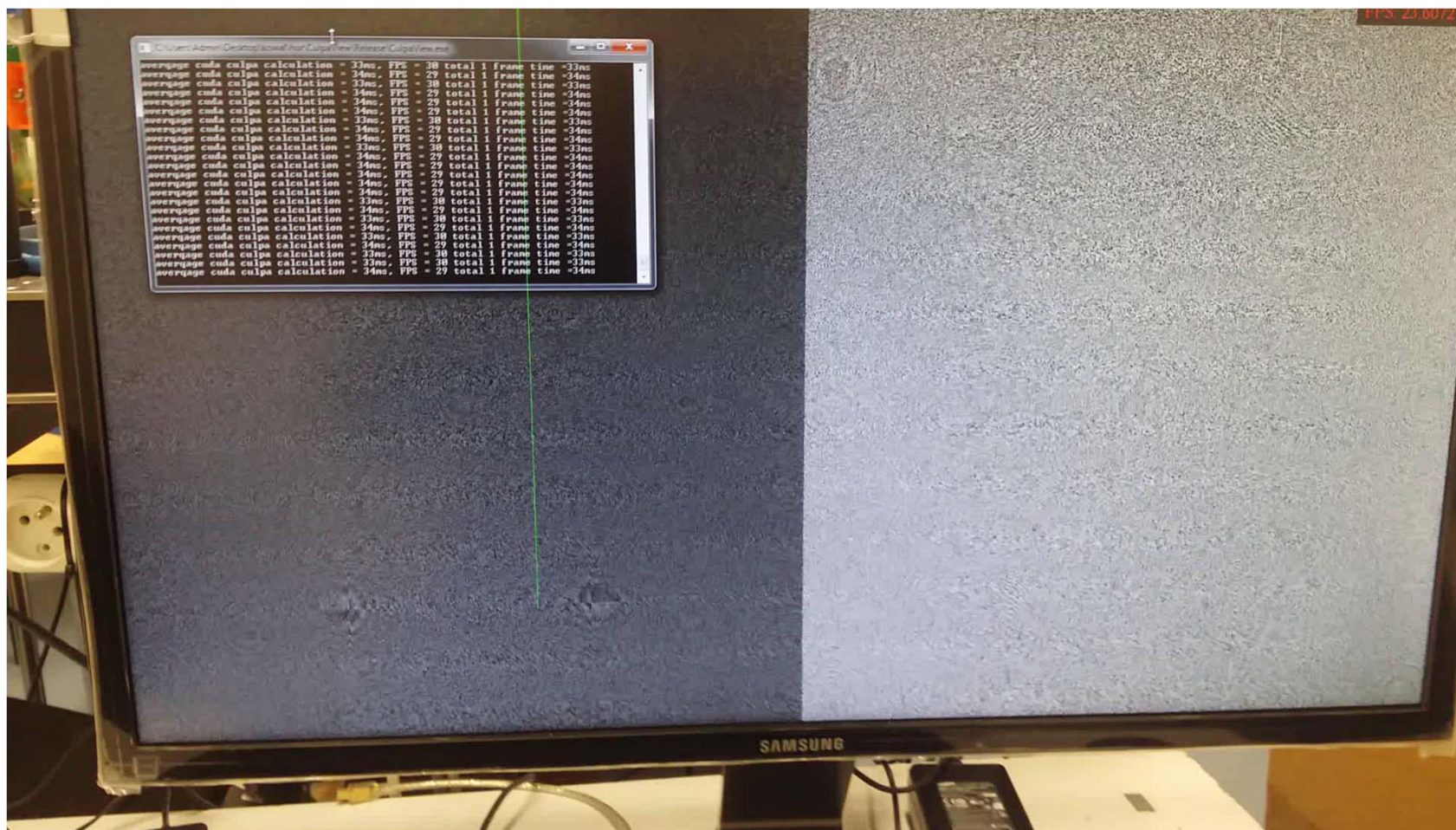
# Holography – many images – far and near

- Two planes of image – both can be seen at the same time.

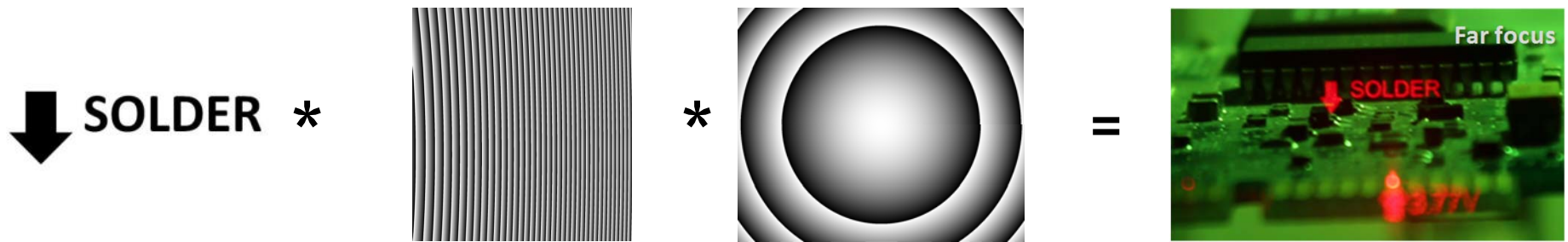




# Two images displayed at the same time



# Hologram generation



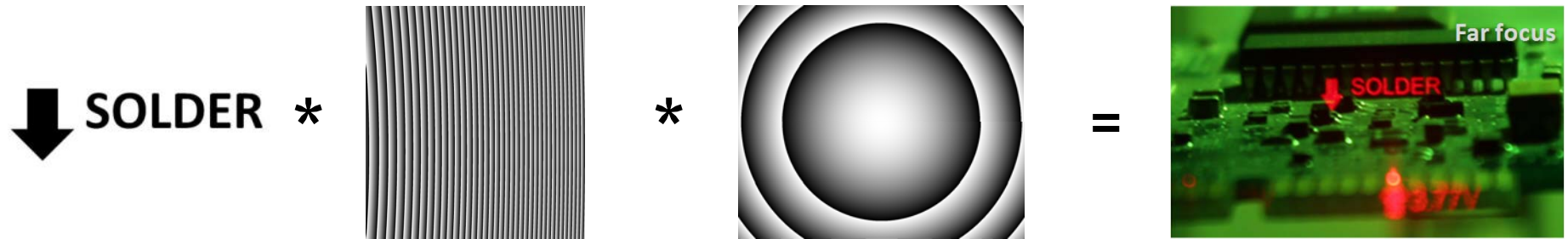
CGH Algorithm  
FFT

XY position

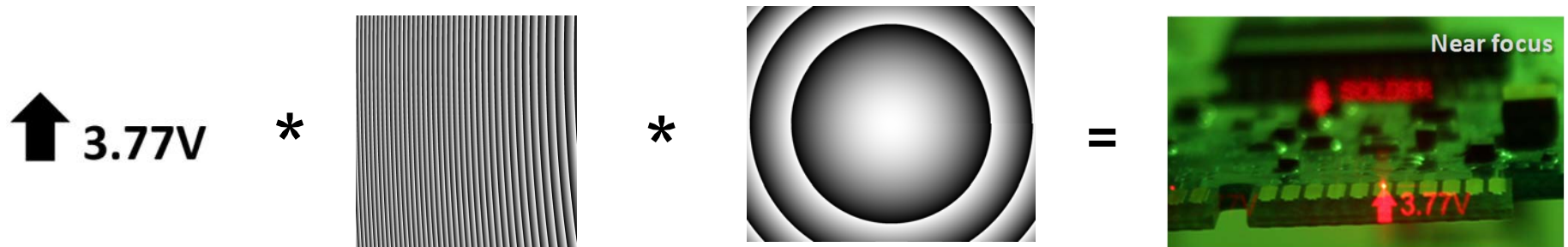
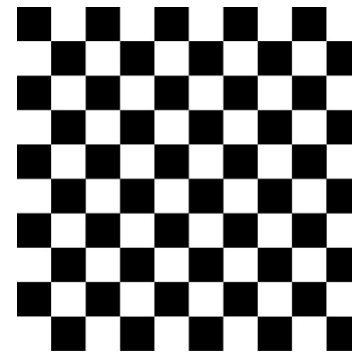
Z position

Result

# Image phase generation



Proces of creation two independent images







# Holographic projection

## PROS:

- Real 3D
- High efficiency („almost“ all light intensity is used for image generation)
- Several image planes is possible

## CONS:

- Extremely expensive
- High computation
- (For this moment) quality is lower than with stereography – „nonlinear quantized movements“
- Need small size of SLM pixels with high fill factor

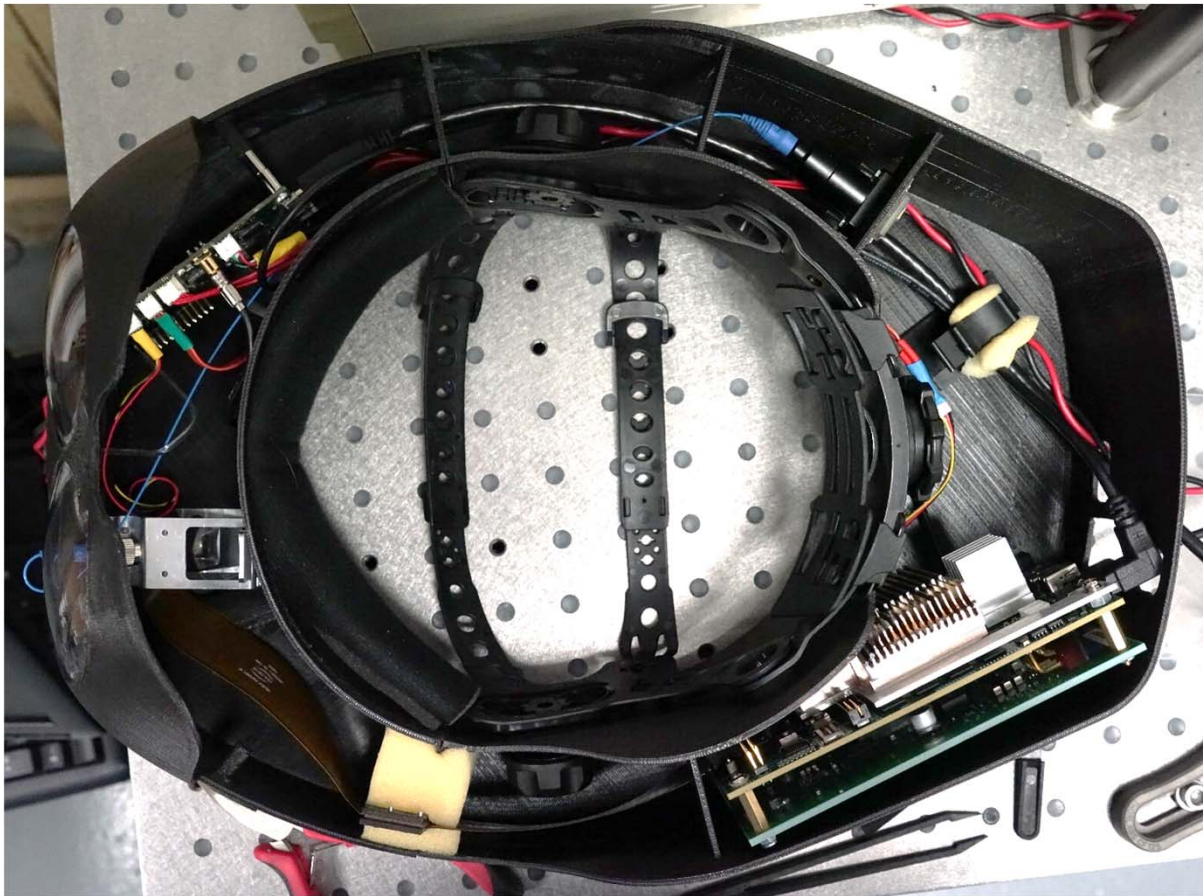
# Developed device



# Prototype description

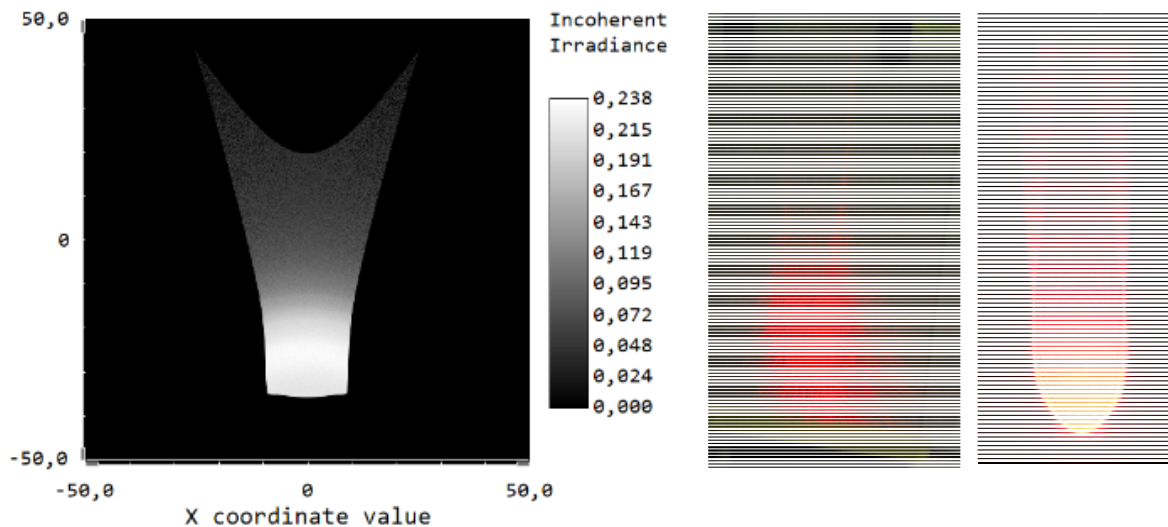


# Prototype description



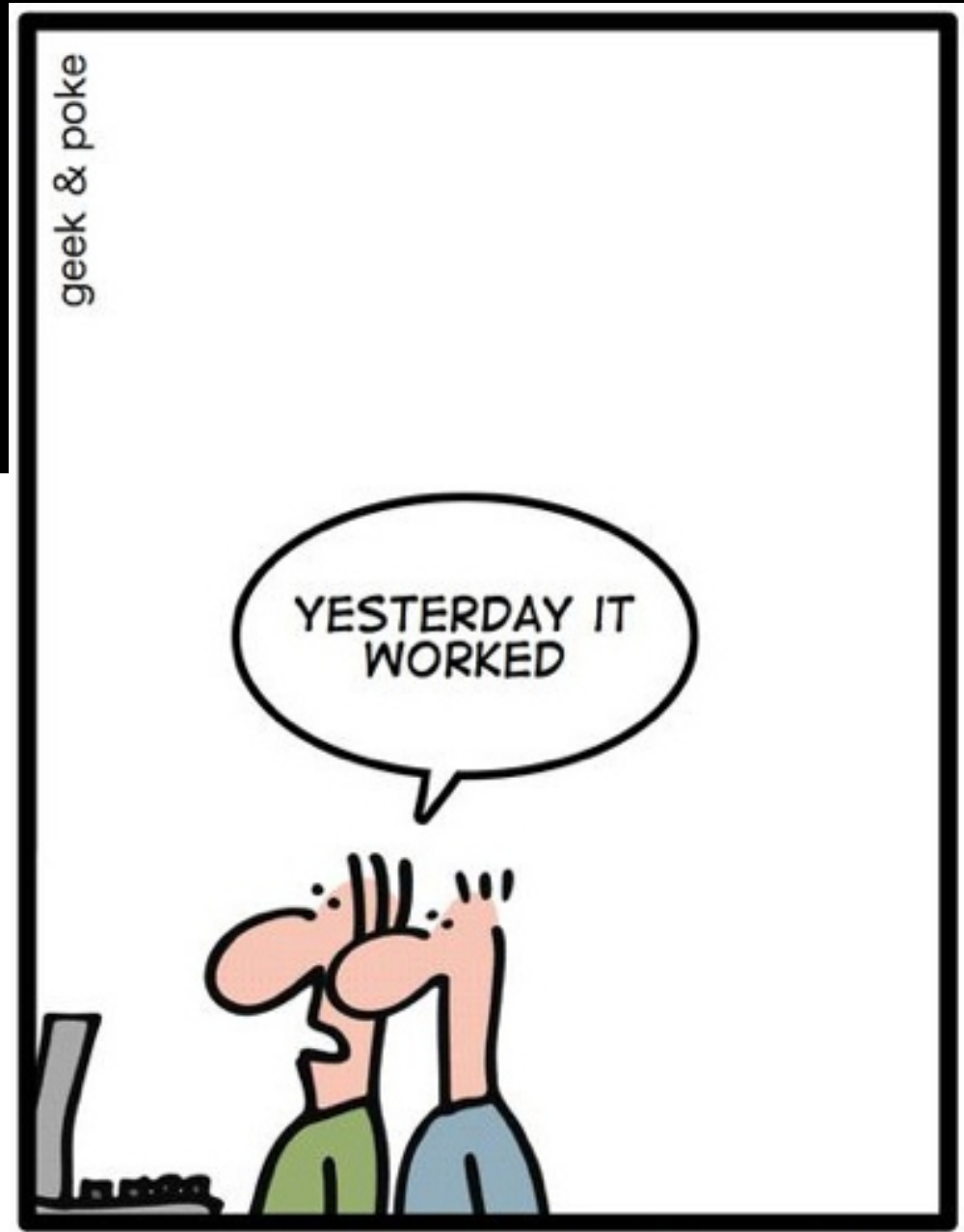
# Key challenge

- Optics manufacturing
  - technology/accuracy
  - Material
  - Time & cost
- Design optimization & verification loop
- Metrology



# Tests and results

# Not-so-live demo





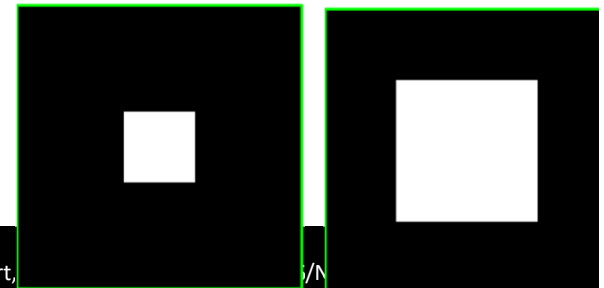
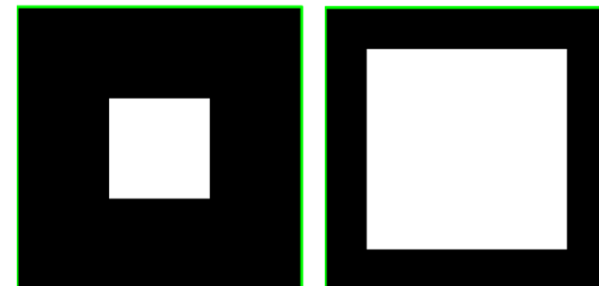
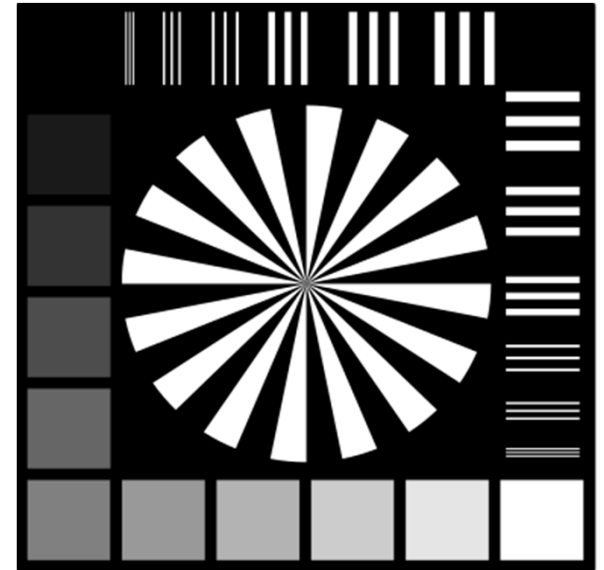
# Look through demo movie

## Symbols



# Tests types

- Quantitative
  - Sensor based
    - Linearity of laser power regulation
    - Received power vs. percentage of filled area
    - Power distribution within the FoV
  - Camera based
    - Power distribution uniformity (histogram and distribution map)
    - Iris brightness profiles
    - Effective resolution, grey levels and minimal line thickness.
    - Contrast and sharpness distribution map
- Qualitative
  - Real users
  - Questionnaires

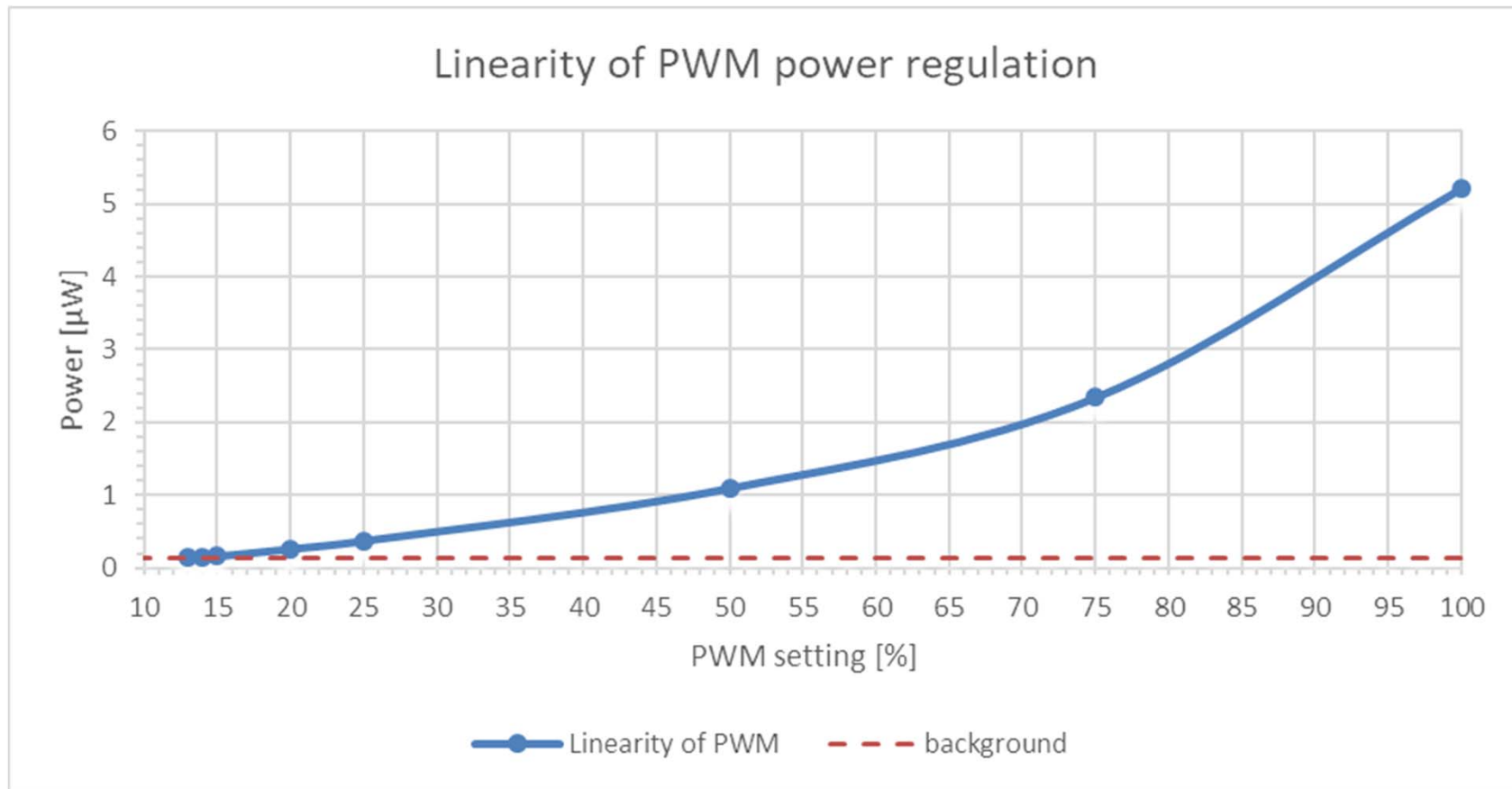


# Quantitative tests setup



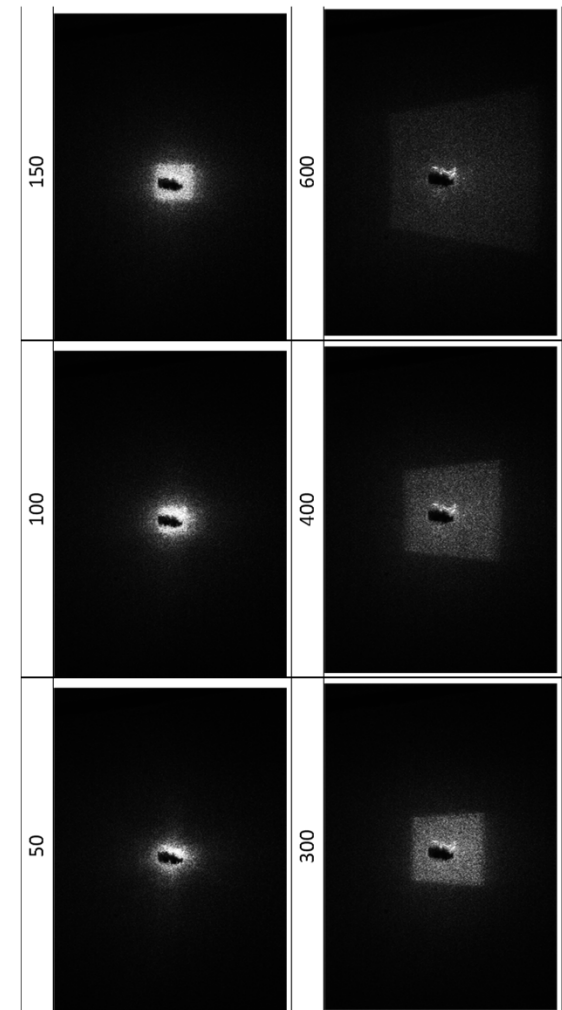
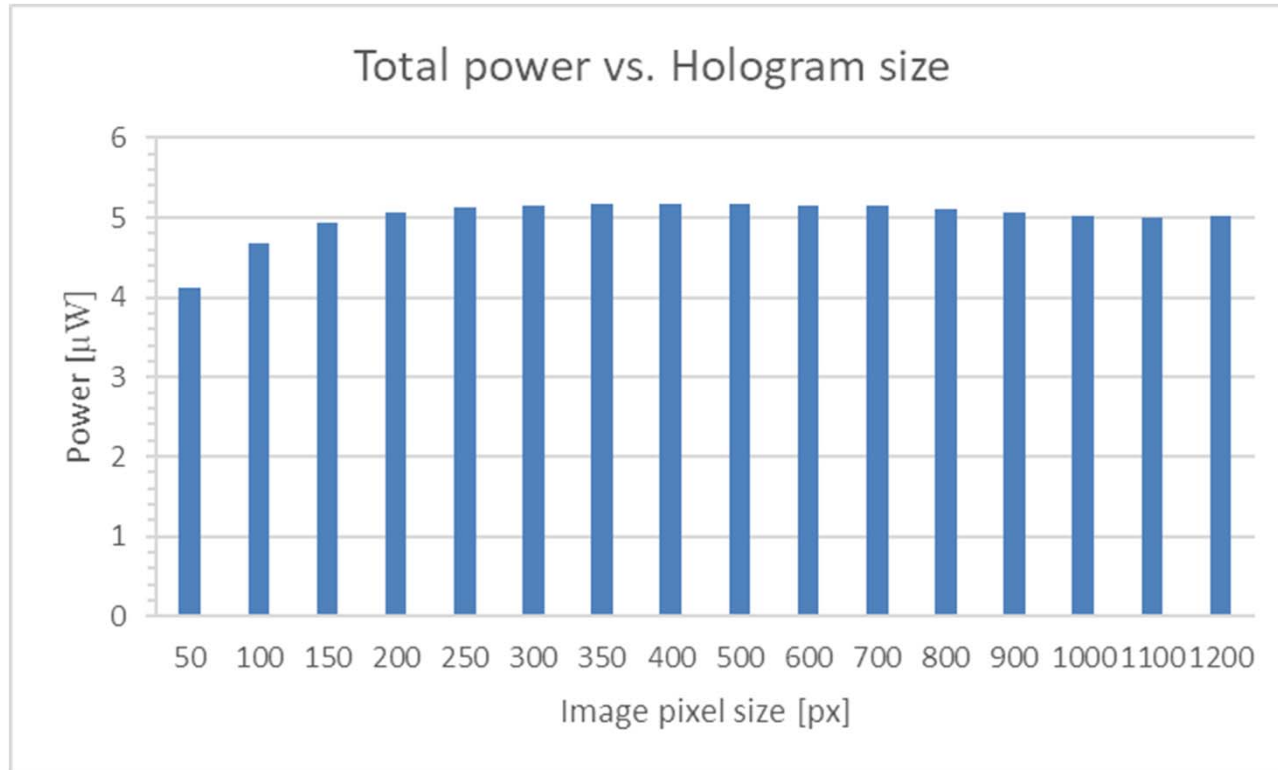


# Results: laser power linearity



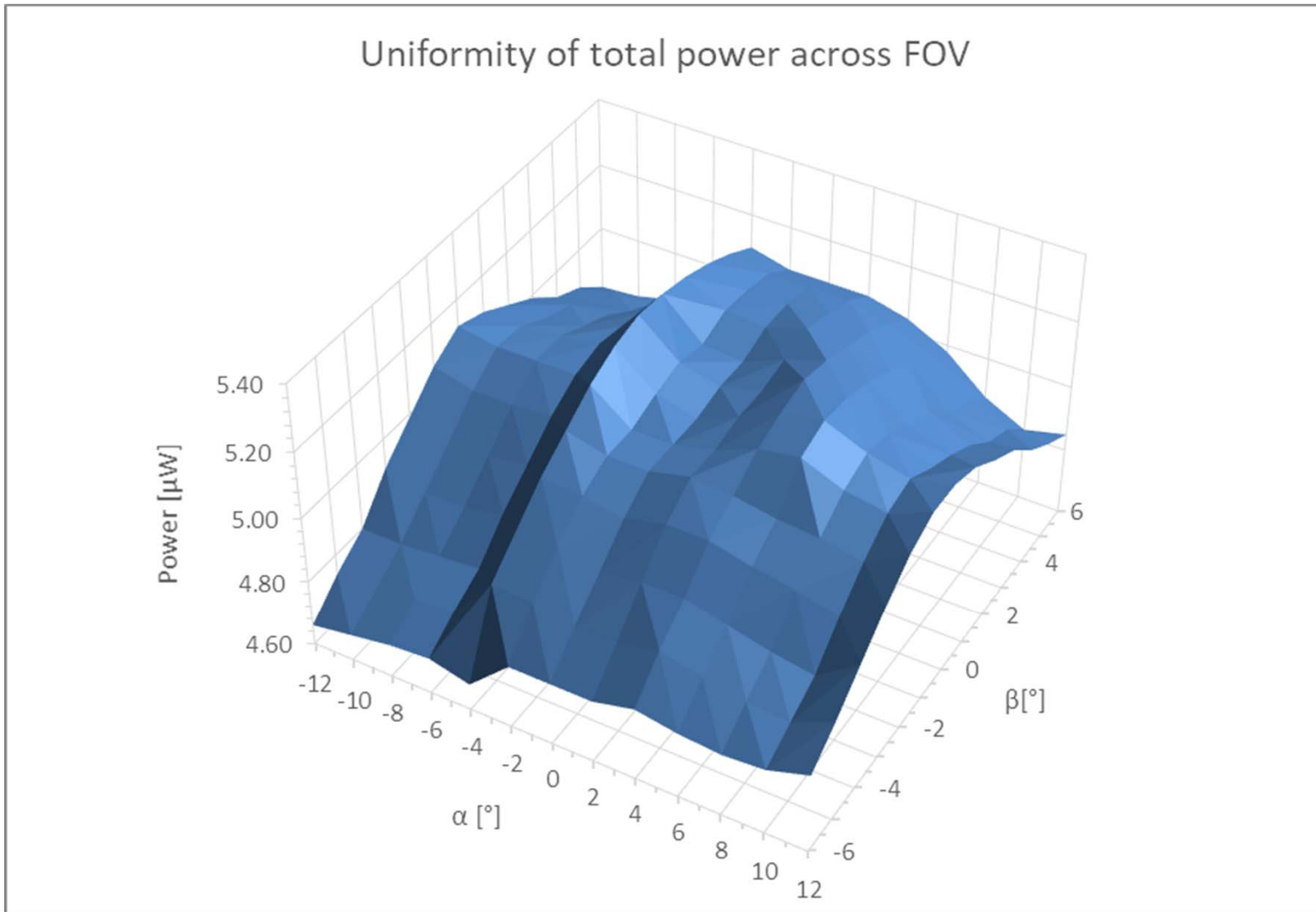


# Results: received power vs. image size



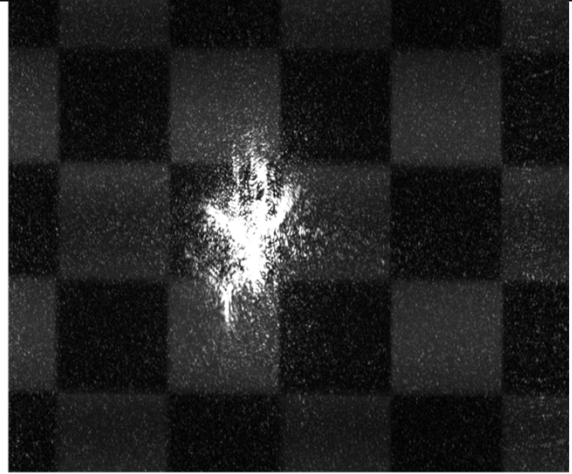
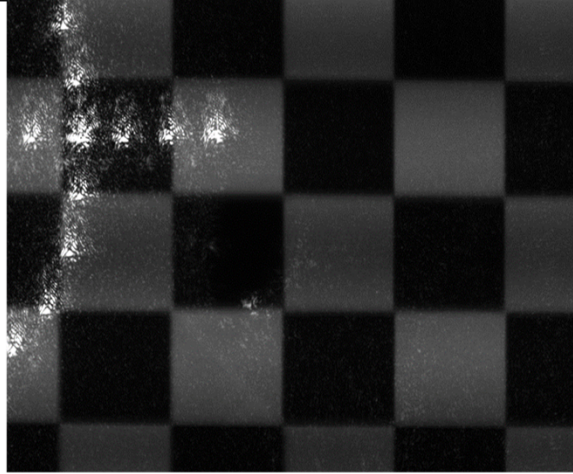
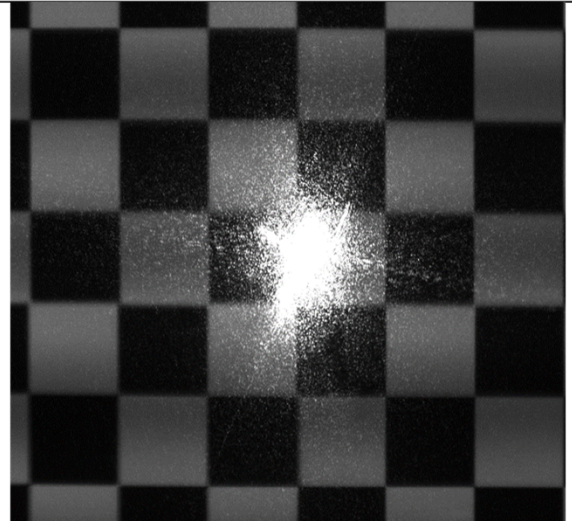
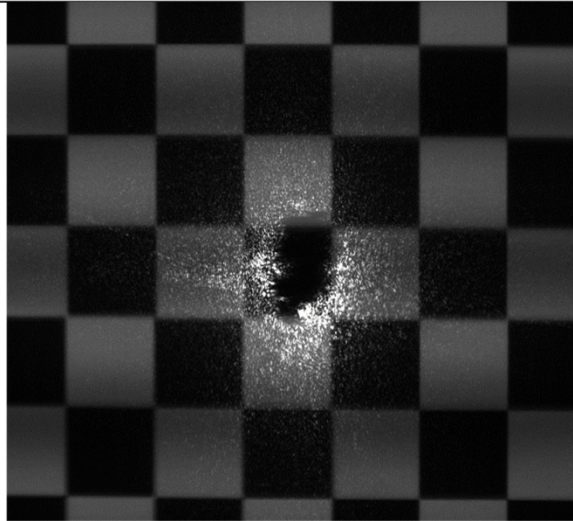


# Results: FoV uniformity





# Results: zero-order filter impact

Without filter	With filter
Hologram displayed	
	
No image displayed	
	



# Image uniformity

Distance: 0.5m, PWM setting: 75% exposure time: 4000us	Distance: 1m, PWM setting: 50% exposure time: 4000us
Distance: $\infty$ , PWM setting: 100% exposure time: 1000us	Distance: 2m, PWM setting: 75% exposure time: 4000us



# Results: contrast and sharpness

Image size: 600px x 600px  
Exposure: 1000 $\mu$ s

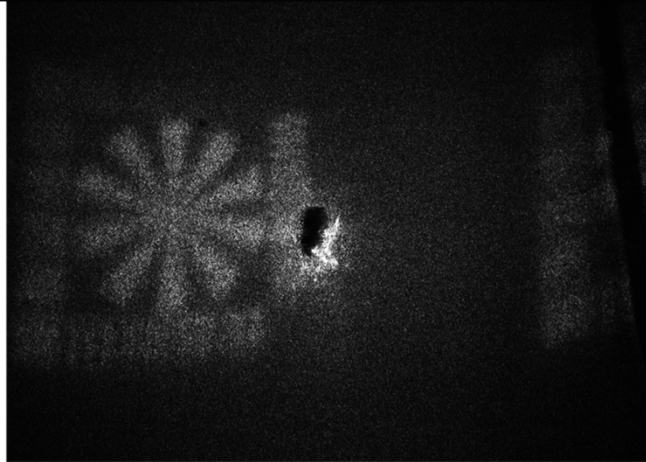


Image size: 600px x 600px  
Exposure: 3000 $\mu$ s

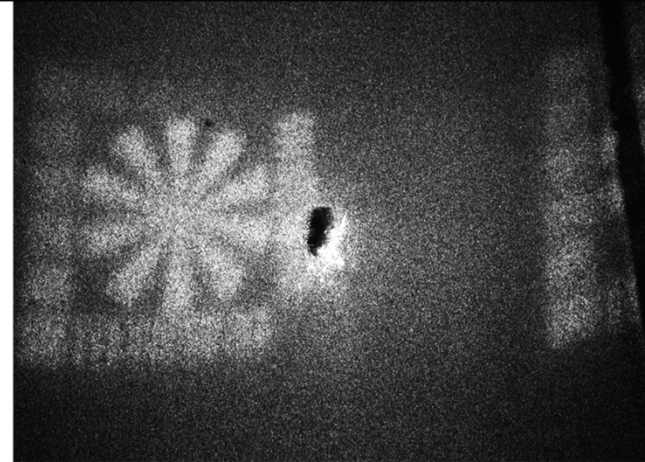


Image size: 700px x 700px  
Exposure: 1000 $\mu$ s

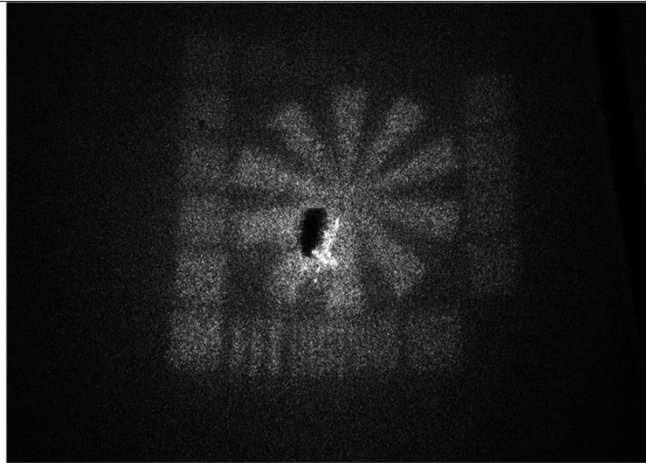
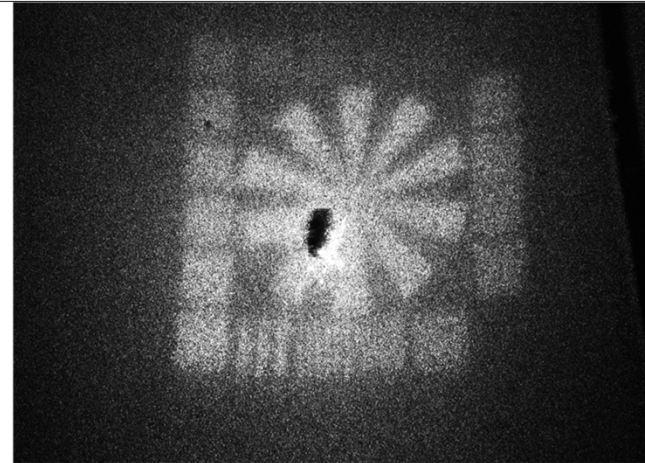


Image size: 700px x 700px  
Exposure: 3000 $\mu$ s





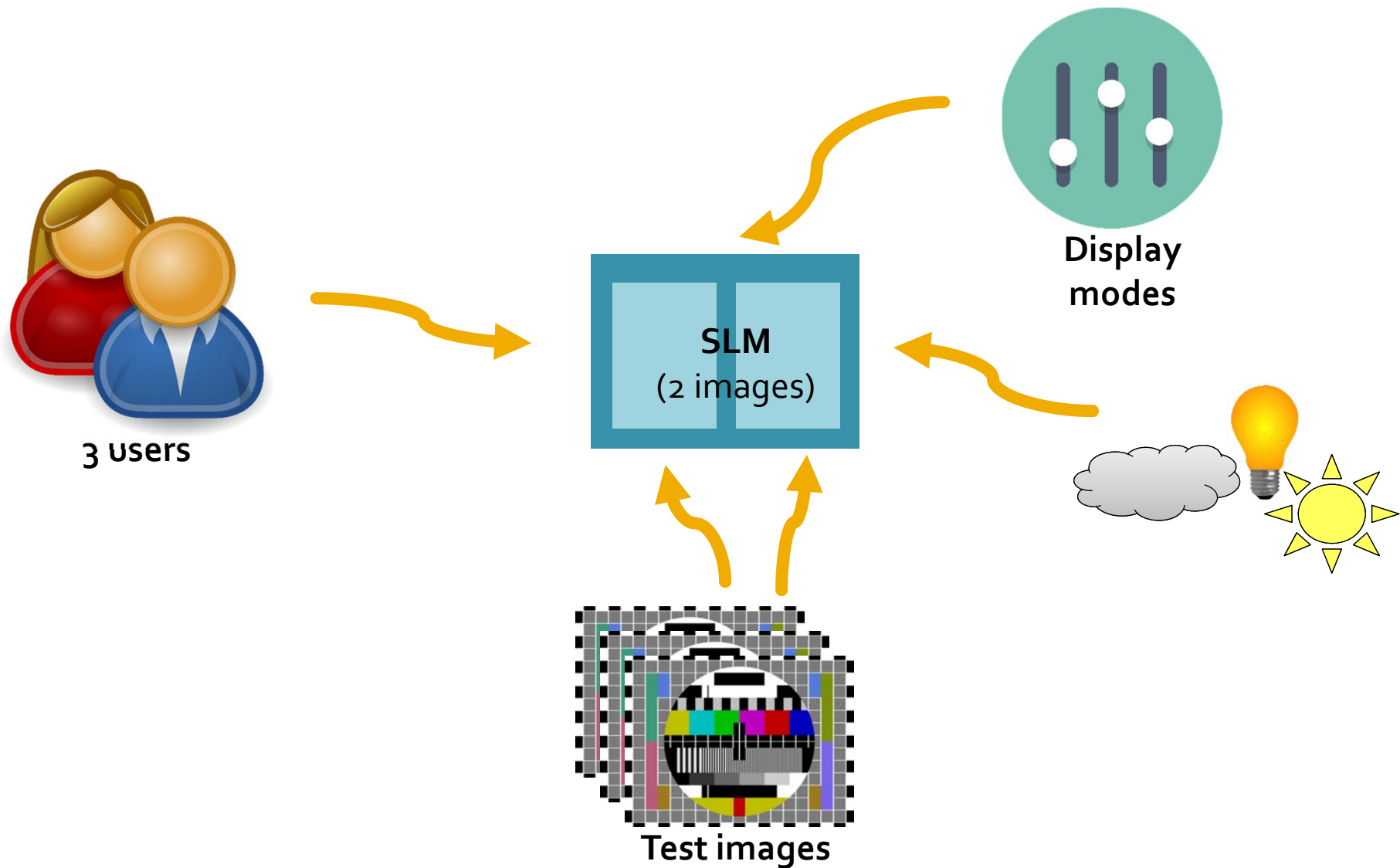


# Results: complexity parameter

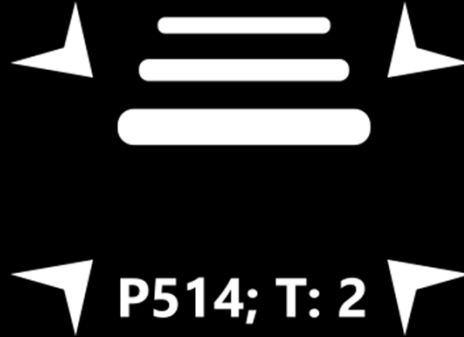
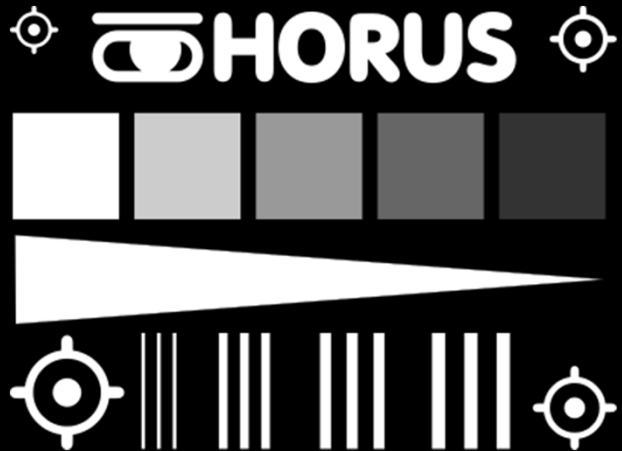
Arrow: 6% HORUS: 94%	Arrow: 12% HORUS: 88%
Arrow: 50% HORUS: 50%	Arrow: 70% HORUS: 30%



# Qualitative perception tests



# Testing pictures



## Testing texts

It is better to keep  
your mouth closed  
and let people think  
you are a fool than  
to open it and  
remove all doubt.

If you tell the  
truth, you don't  
have to remember  
anything.

The secret of  
getting ahead  
is getting  
started.



# Qualitative: evaluation

- User filled questionnaires
- 1..5 grades for each combination tested
- Sample questions
  - Overall reception quality
  - Detail level
  - Text readability
  - Image overlay impression
  - Object following impression
  - Animation quality
  - Disturbances
  - Sight comfort
  - Sight fatigue
- Subjective comments and suggestions





# Test matrix

ID	Left image	Left mode	Right image	Right mode	Light	Variables	Questions
1	S1	SD <sub>4</sub> , L8			x	x=D,M,B,S	1,2
2			S1	SD <sub>4</sub> , L8	M		1,2,18,19
3	S2	SD <sub>4</sub> ; Lx			M	x=1..9	5
4	Tx	SD <sub>4</sub> ; L2			M	x=1..3	2,3,7
5	AS1	SD <sub>1</sub> ; L5			M		2,3,4,12,13
6	ST1	SD <sub>1</sub> ; L8			M		2,12,13
7	ST2	SD <sub>2</sub> ; L8			M		2,12,13,18,19
8	GS	SD <sub>4</sub> ; L4			M		14,15
9	S3	VD			M		2,3,4,7,9
10	S3	UC			M		2,6,7,8,10
11	S4	AD; L5			M		2,10,17
12	S4	OA			M		9,10,16,11,18,19
13	S5	AD; L5; C30	T2	S4; L2; C70	M		2,7,10,11
14	S4	UC; C30	ST1	S1; L2; C70	M		2,6,8
15	AS1	OA; C60	T3	S4; L9; C40	M		2,9,11,13,16,17
16	ST2	S4; L7; C80	AS1	OA; C20	M		2,4,9,13
17	S3	OA	S1	OA	M		4, 10, 16,17,18,19

Test images		Ambient light		Display mode	
Greyscale	GS	Dark (~200 lux)	D	Static distance (0.5, 1, 1.5, inf)	SD x
B&W symbol (1..4)	Sx	Medium (400-500 lux)	M	Variable distance	VD
Animated symbol (1..2)	ASx	Bright (>700 lux)	B	Predefined location	Lx
Static text (1..3)	Tx	Daylight with sun	S	User controlled (location, distance, size)	UC
Scrolling text (1..2)	STx			Auto distance	AD
				Anchored to object	OA



# Questions

ID	Question	Scale (1..5)
1	How bright is the symbol as compared to the background	Very dark .. very bright
2	What is overall readability of the symbol/text	Very bad .. very good
3	What is visibility of symbol/text details	Very bad .. very good
4	How distracting is the glow around symbol/text	Very distracting .. not distracting
5	Is the whole symbol/text visible	No or small fraction visible .. fully visible
6	Are the filled areas of the symbol uniform	Very ununiform .. very uniform
7	Are the edges of symbol/text sharp	Very blurry .. very sharp
8	How easy it is to focus sight at the symbol/text	Very hard .. very easy
9	How easy it is to follow the changing focus of the symbol	Very hard .. very easy
10	How does the symbol/text obstruct the view in behind	Very obstructive .. not obstructive
11	Is it possible to focus at the symbol/text and surface behind at the same time	Very hard .. very easy
12	Is the animation/scrolling smooth	Very freezing .. very smooth
13	Does animation/scrolling obstruct environment reception	Very obstructive .. not obstructive
14	Is the content of the greyscale image clearly visible	Hardly visible .. clearly visible
15	Are the greyscale levels in the image distinguishable	Not distinguishable .. well distinguishable
16	How well is the symbol/text following real object	Very bad .. very good
17	How natural appear the symbol at the real object	Very unnatural .. very natural
18	How is your eyesight tired	Very tired .. not tired at all
19	How is your neck tired	Very tired .. not tired at all
20	Does the second symbol/text obstruct reception of this one	Very obstructive .. not obstructive

# Testing team

S1



- Attitude is important!

S2



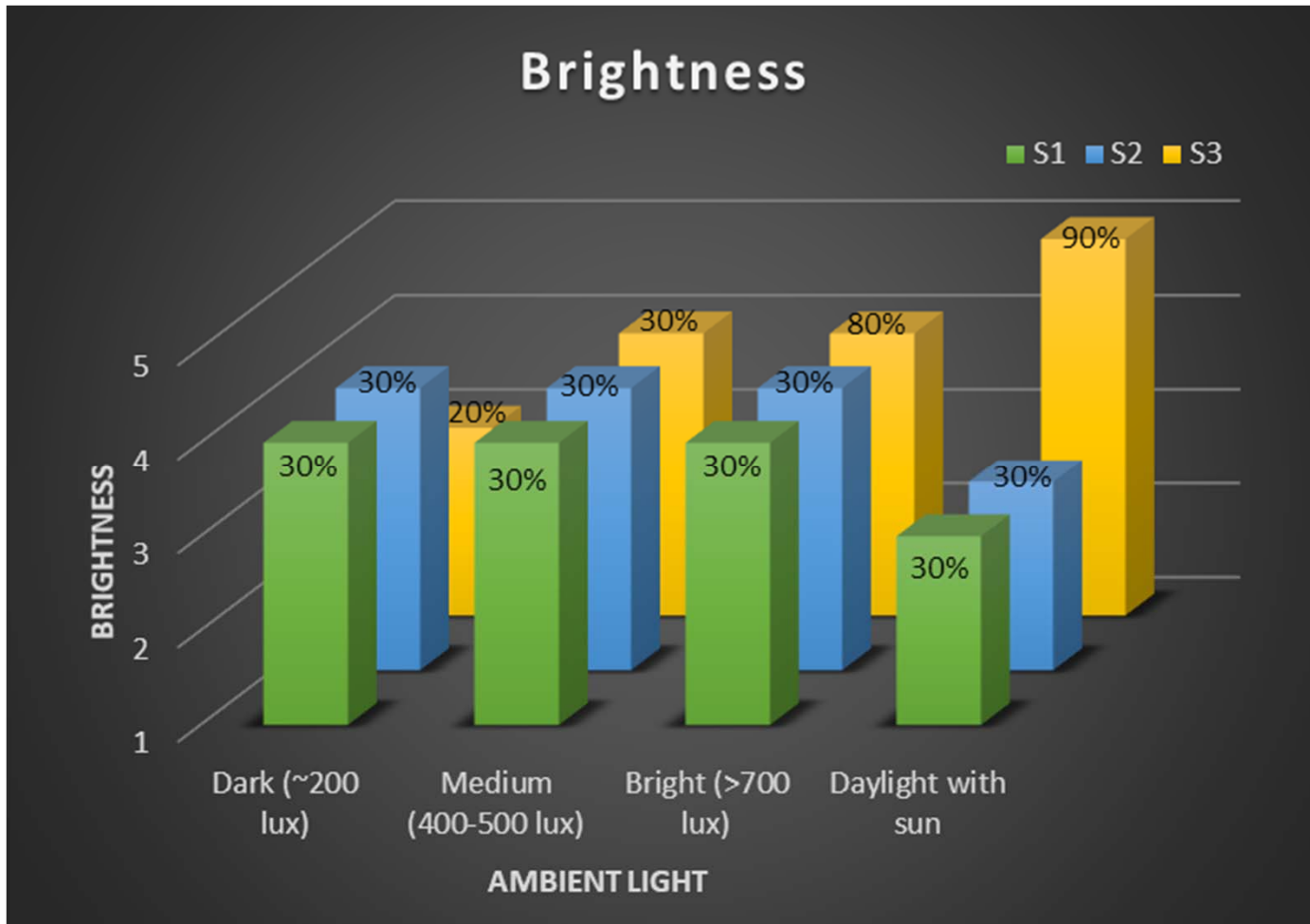
S3





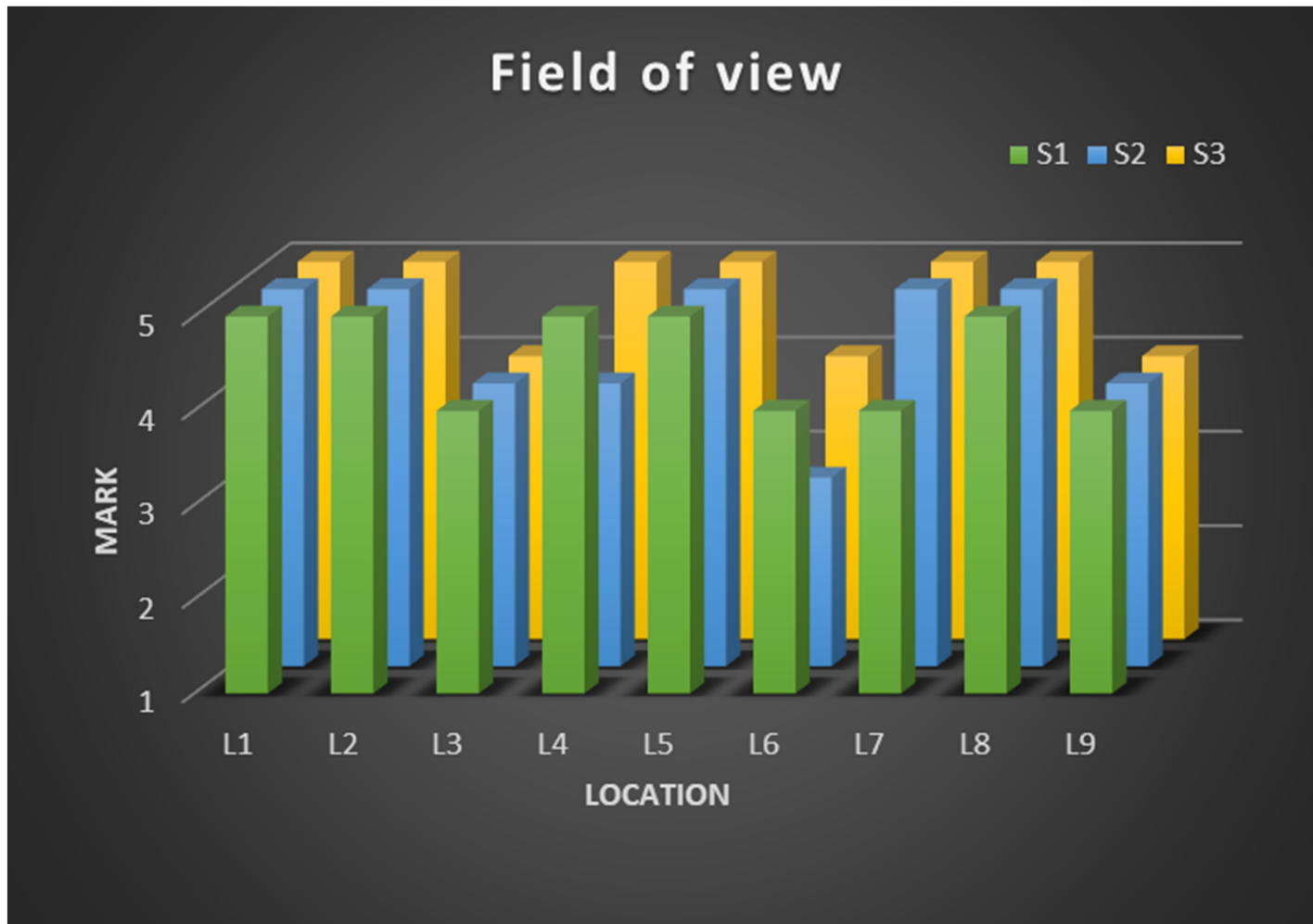


# Test results



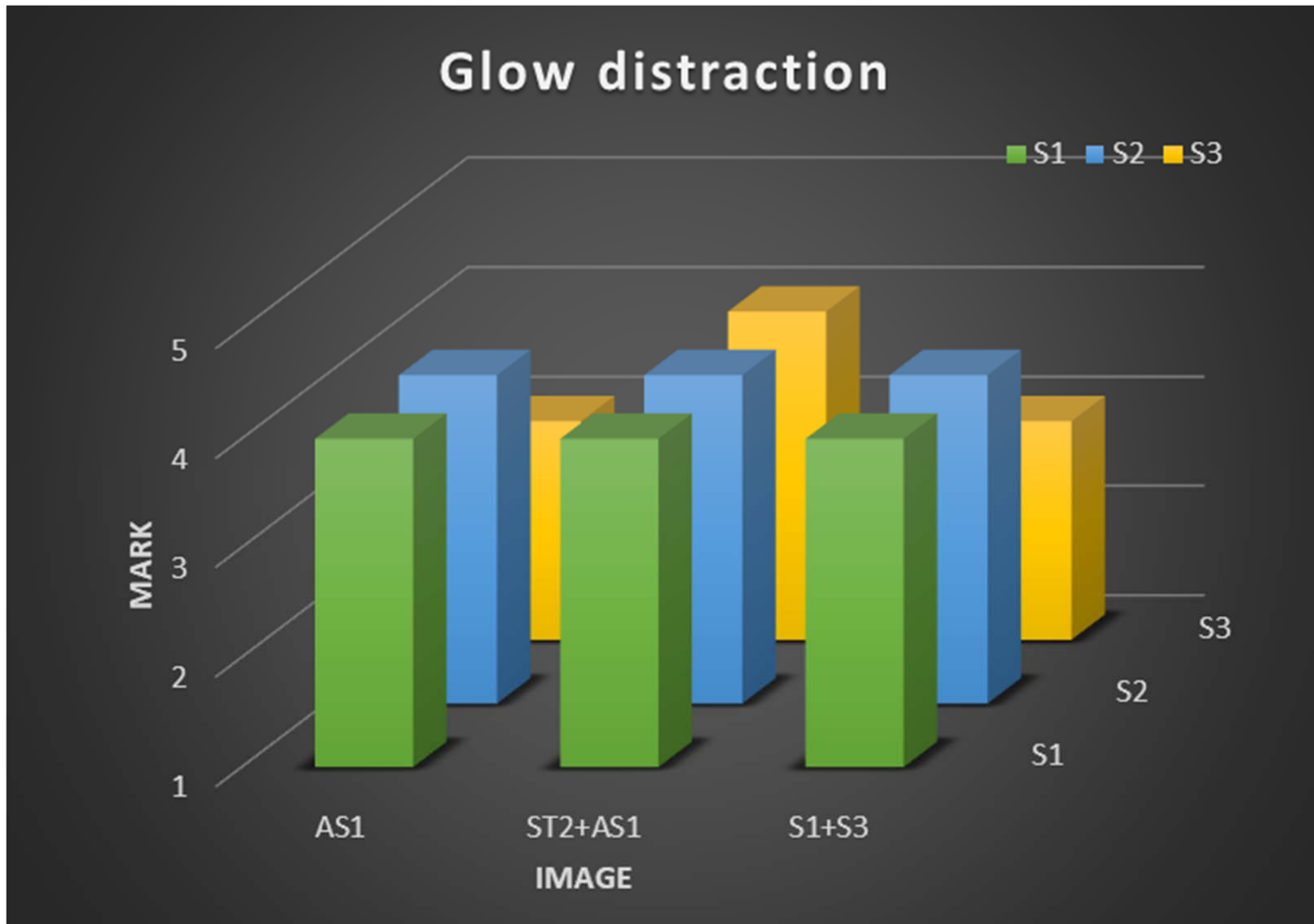


# Test results



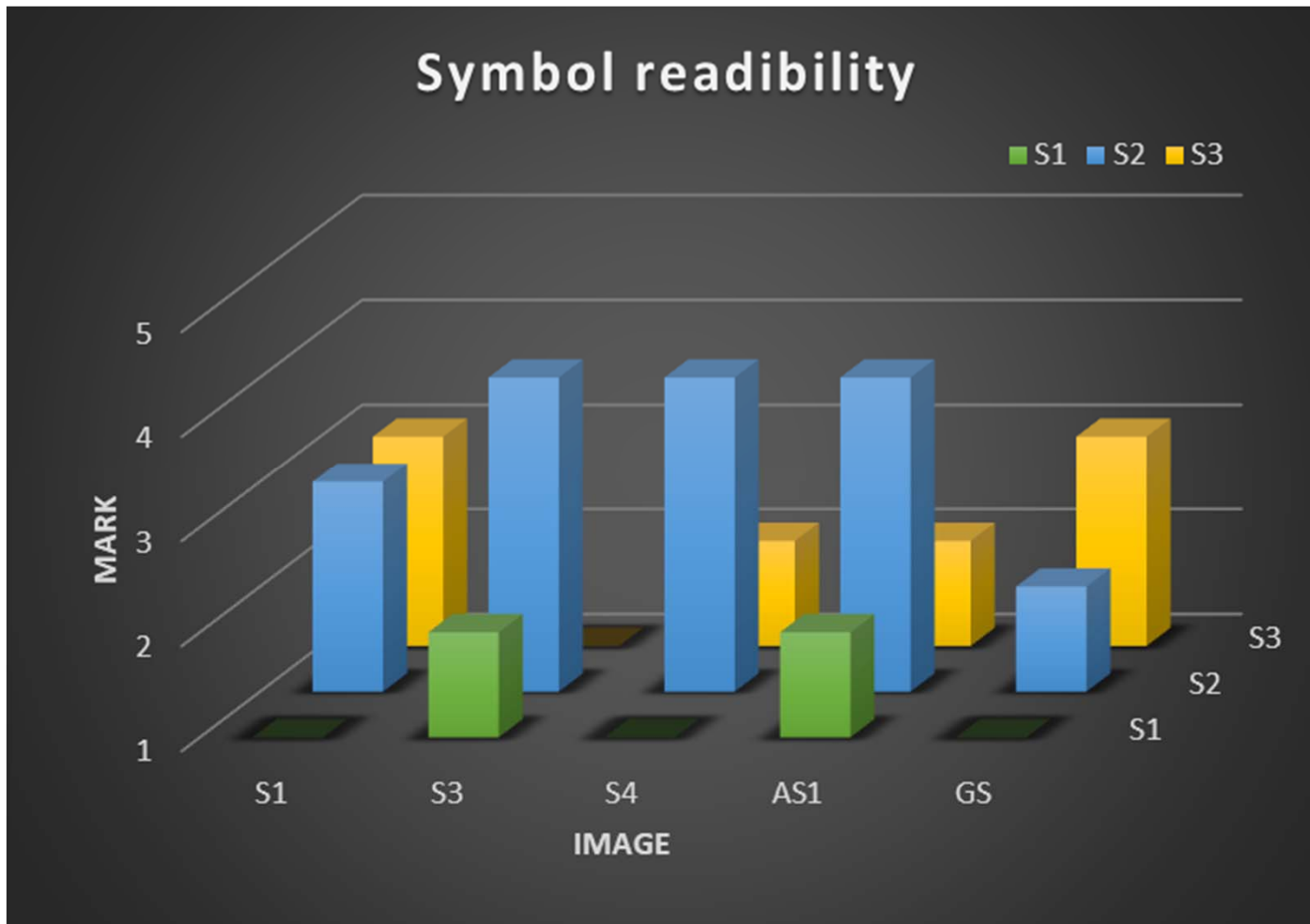


# Test results



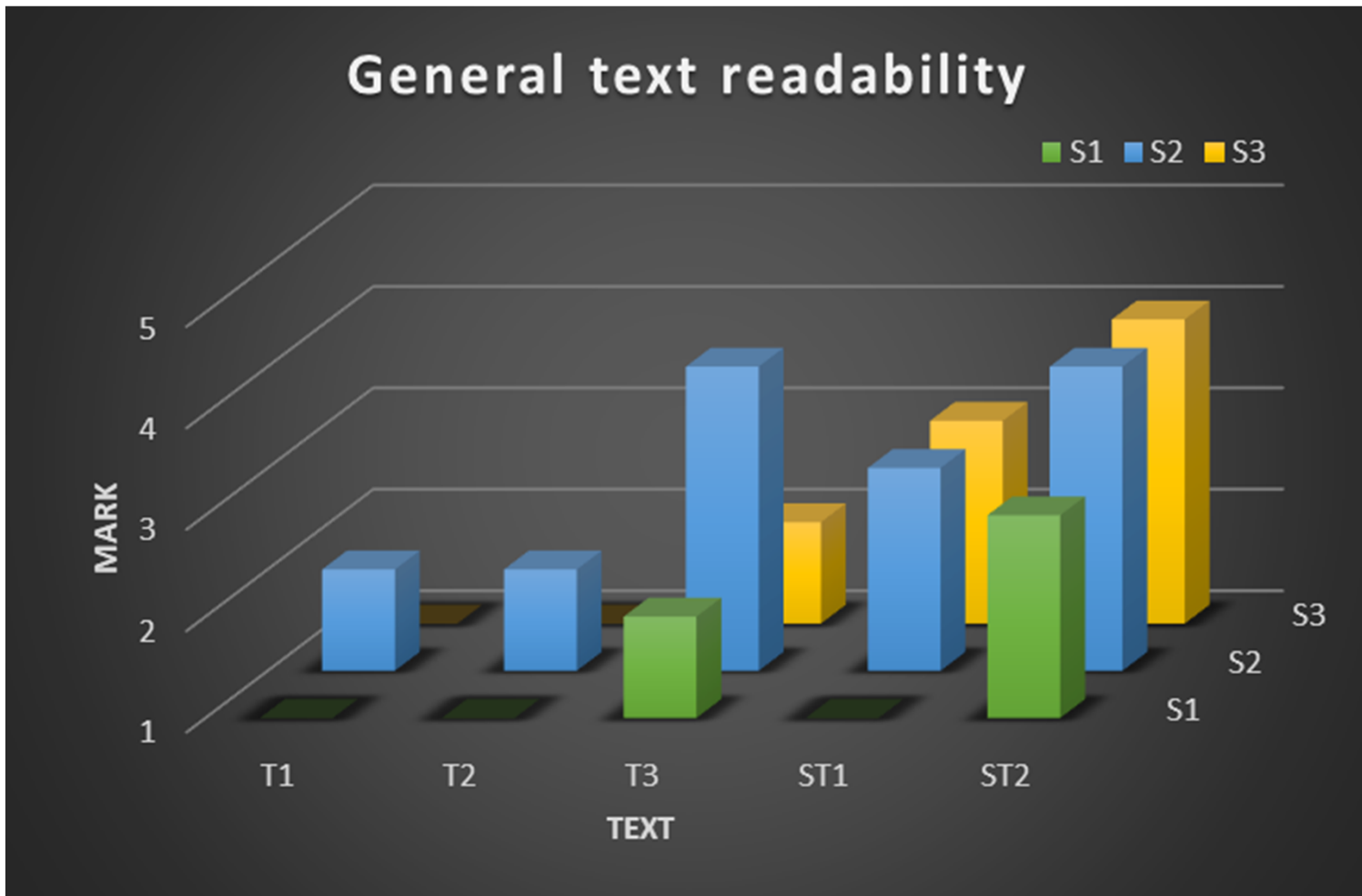


# Test results



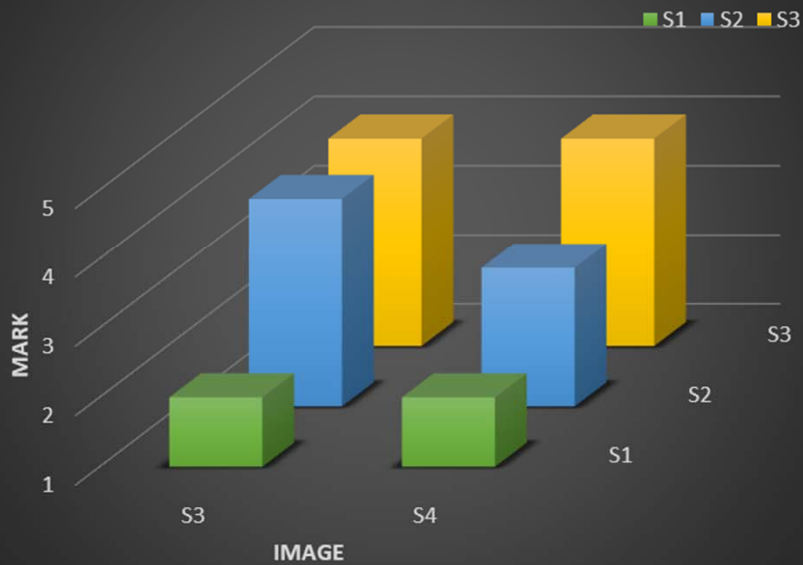


# Test results

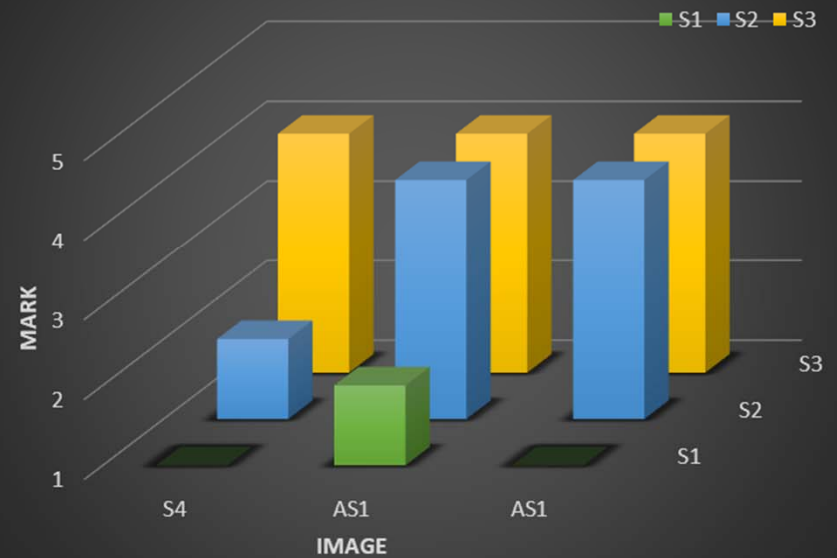


# Test results

### Sight focusing on symbols

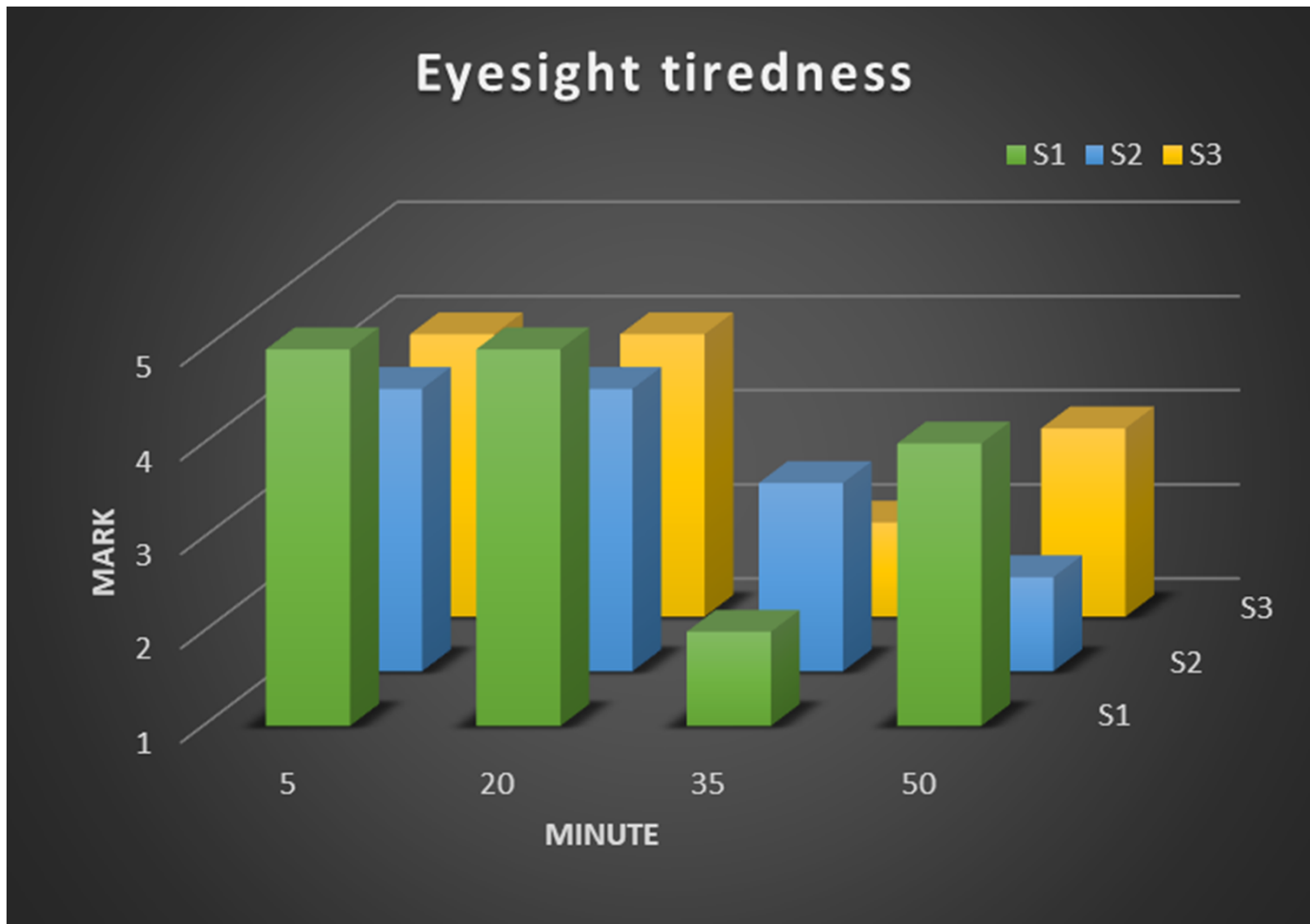


### Focus following



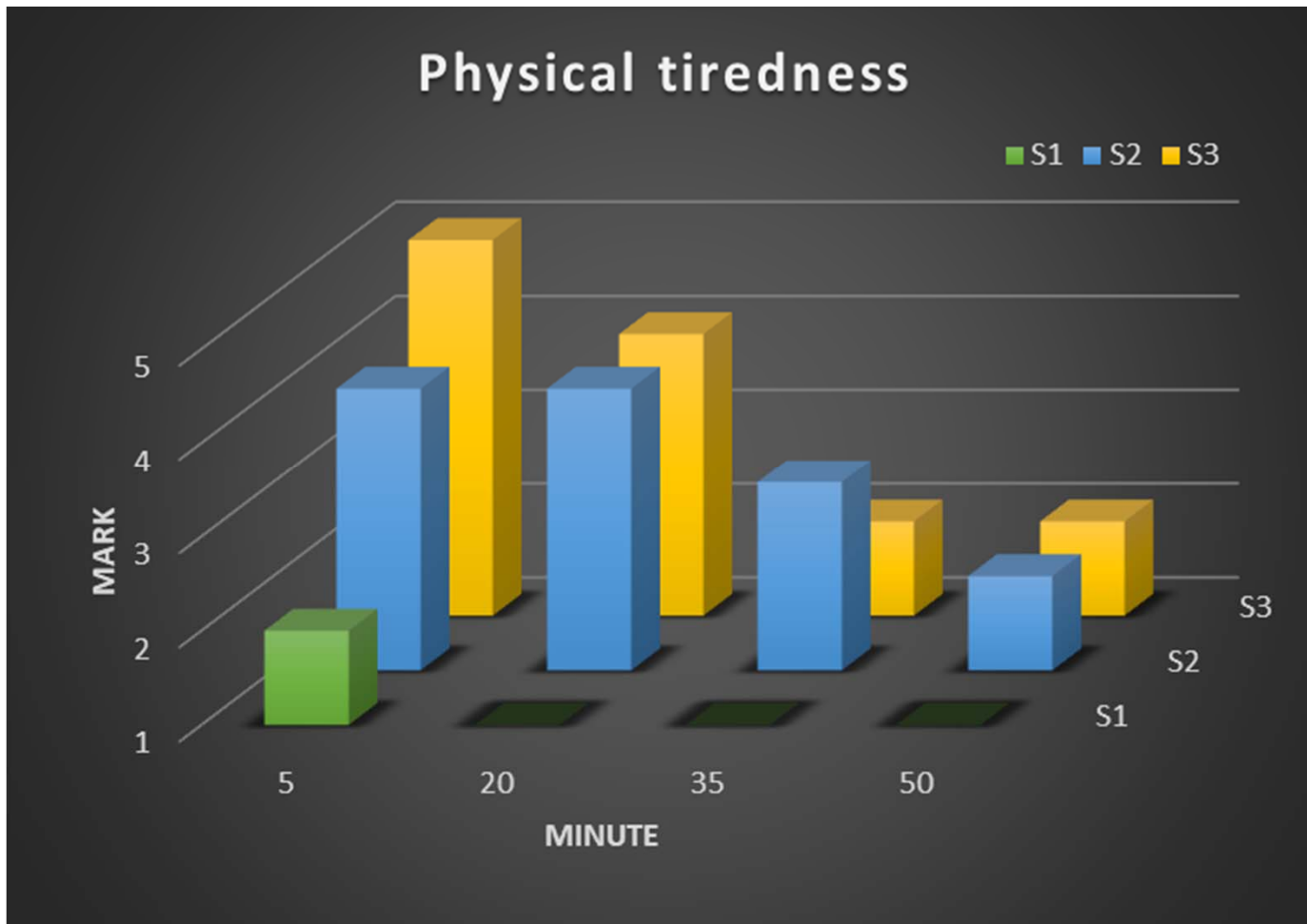


# Test results





# Test results



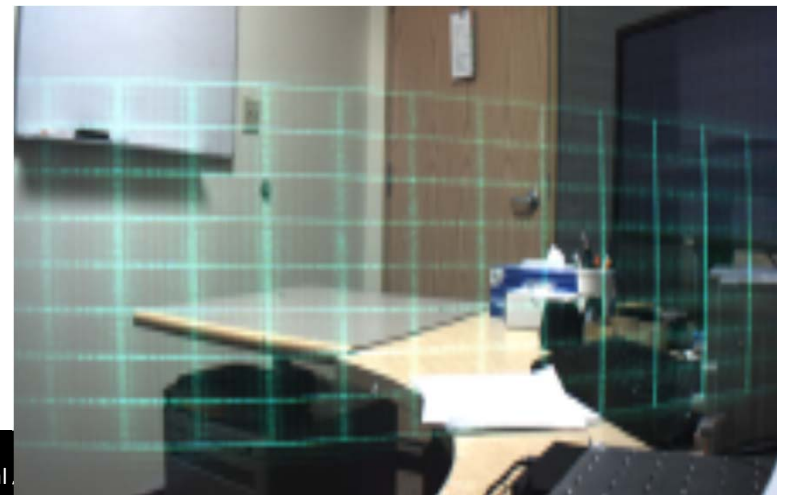
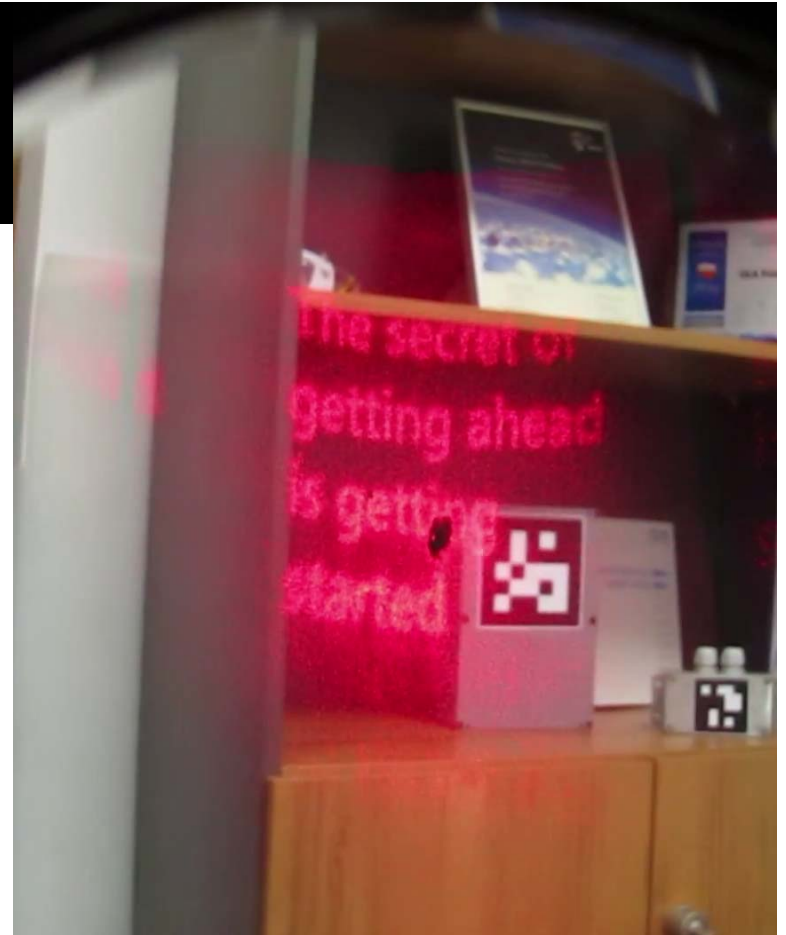


# Conclusions



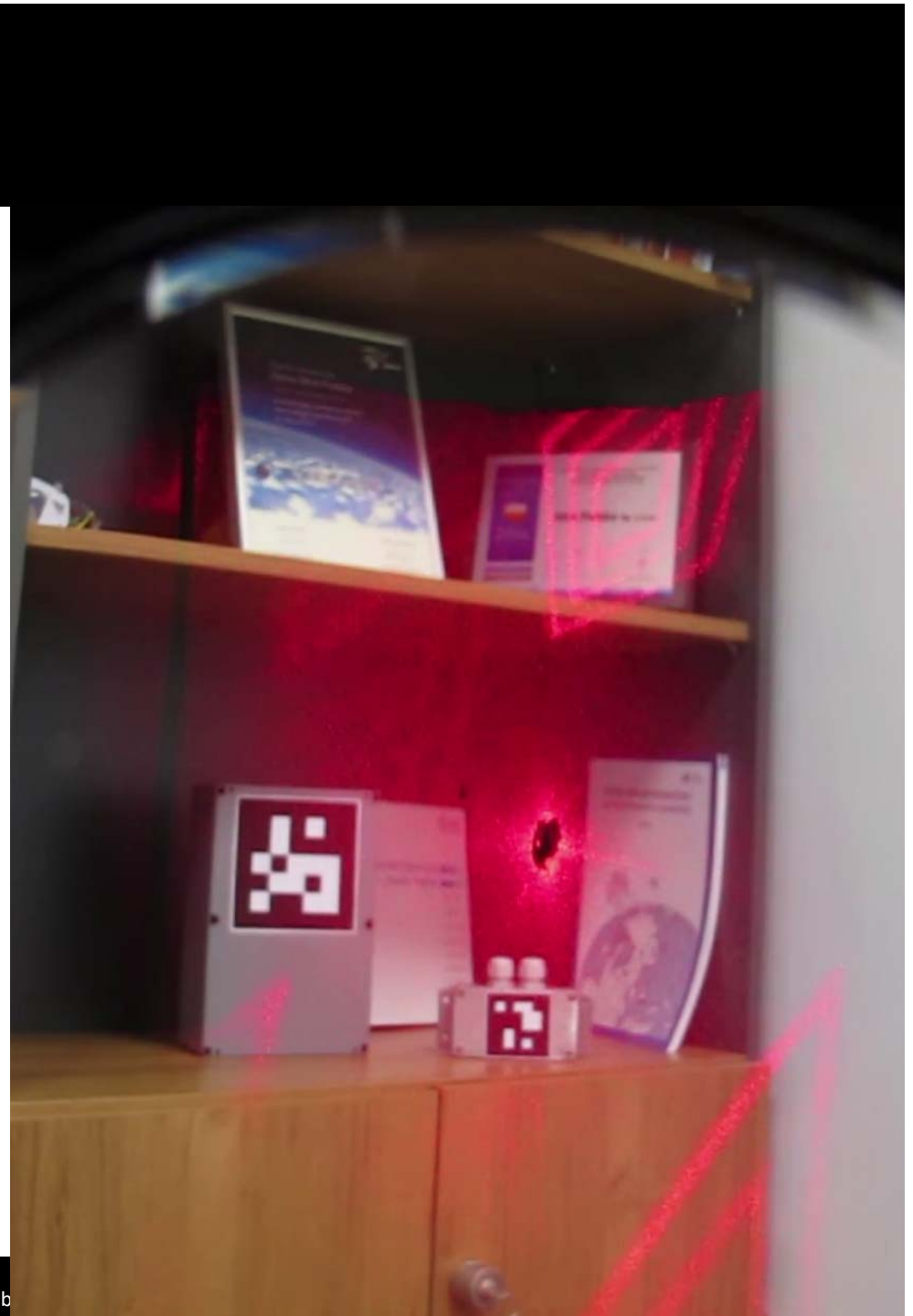
**" Don't jump to conclusions, Mom . .  
looks can be deceiving. "**

- Device works!
- Assumed functionality is achieved
- Assumed FoV is achieved
- Laser safety class 1
- Image quality is too low for serious applications
  - Known sources, possible to solve
  - Latest research confirms it (Microsoft)



# Optics

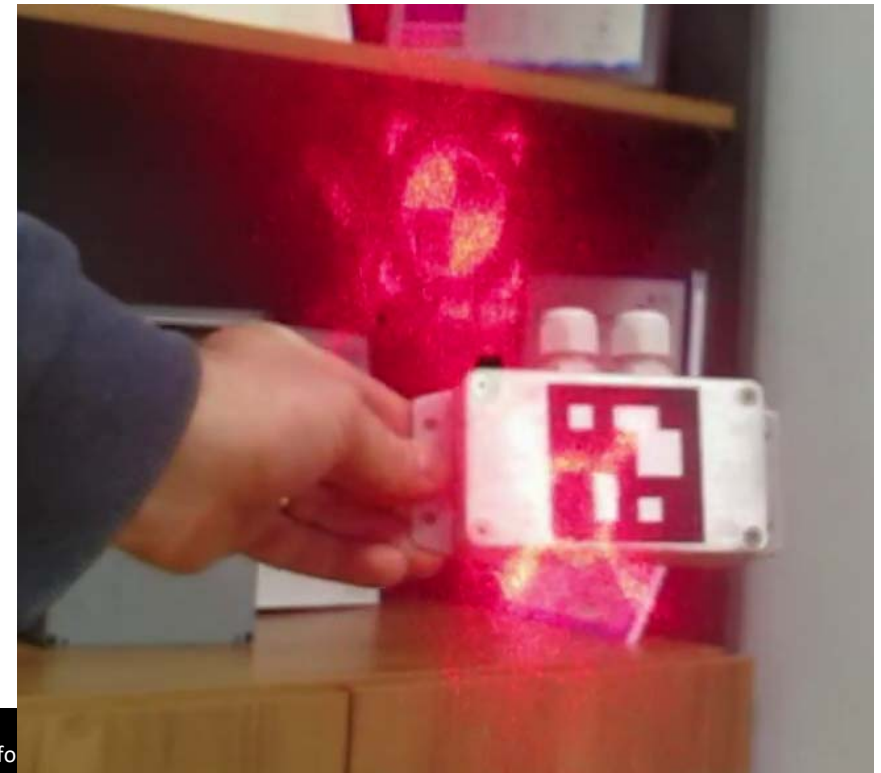
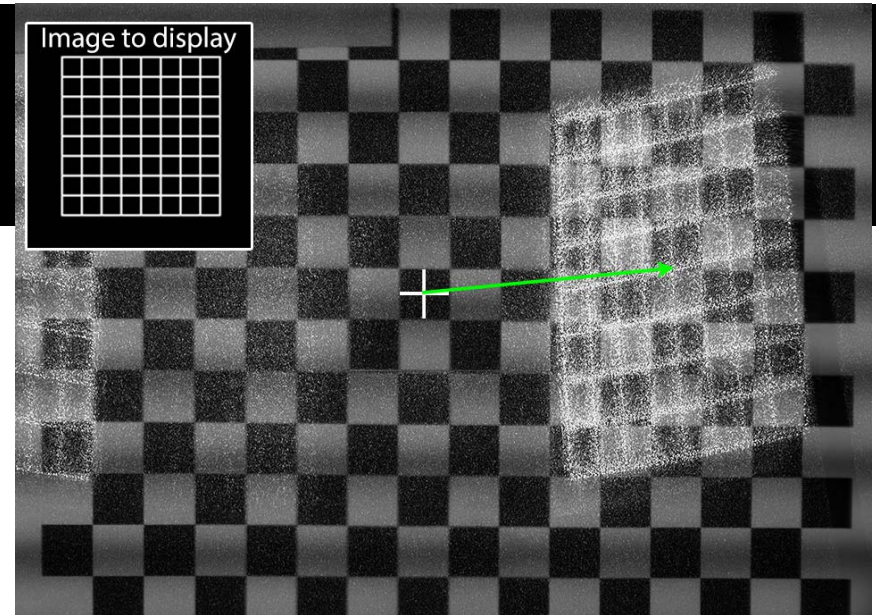
- Design confirmed
- Zero-reflection size – resolution limit
- Free-form elements manufacturing and verification
  - prototype and full scale
  - combiner
- Internal reflections and higher order deflections is to be rethought
- Zero-filter edges
- SLM aperture workaround
- Further zero limiting – gating
- Personal mechanical adjustments
- Eyesight wear – hard to say



- Device is big and heavy
  - Reduction potential
- Uneven mass distribution
- More individual adjustments
- Cables – not a problem



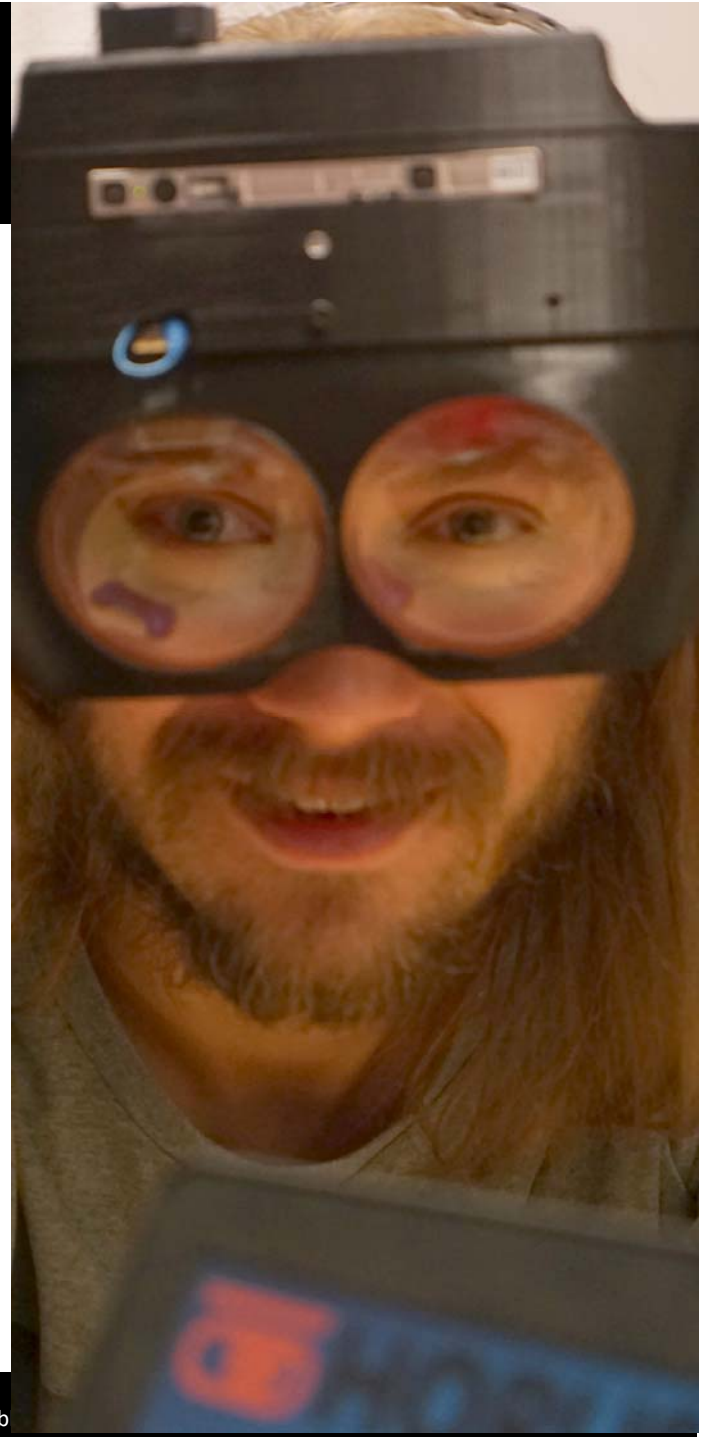
- Hologram generation
  - Always too slow
  - Better scheme for speckles averaging
- Application software
  - Per user calibration method
    - Camera calibration
    - Image rectification
  - IMU for motion prediction
  - Continuous laser and image power adaptation
    - Ambient light
    - Local intensity
    - Covered area





# User experience

- Image easy to find after seen first
- Single-eye
  - Not intuitive, but to get used to
  - Pros and cons?
- Variable focal plane hardly spottable (SLM aperture effect)
- Multi-reflections
- Animations – received better
- Glow – not that distracting
- Greyscale – not this time
- Generally doesn't obstruct view
- Current combiner limits FoV





## Further development directions

- Optics manufacturing!
- FPGA based hologram calculation
- Miniaturized SLM controller
- Color (R,G,B lasers multiplexing)
- Next generation SLM
- Wireless communication
  
- Most important obstacle
  - Current SLM production scale (affects price, size)

# Questions

