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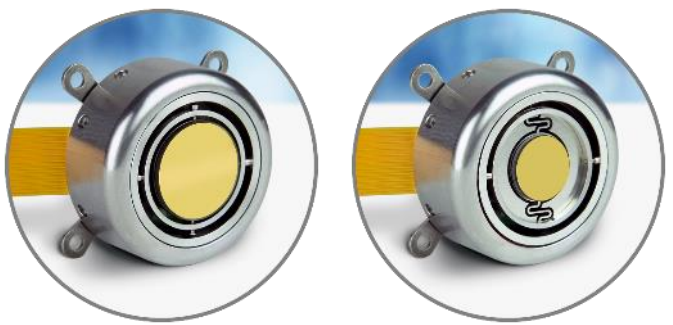
Optotune mirror presentation

Technology – Products – Applications



Zurich, August 2021

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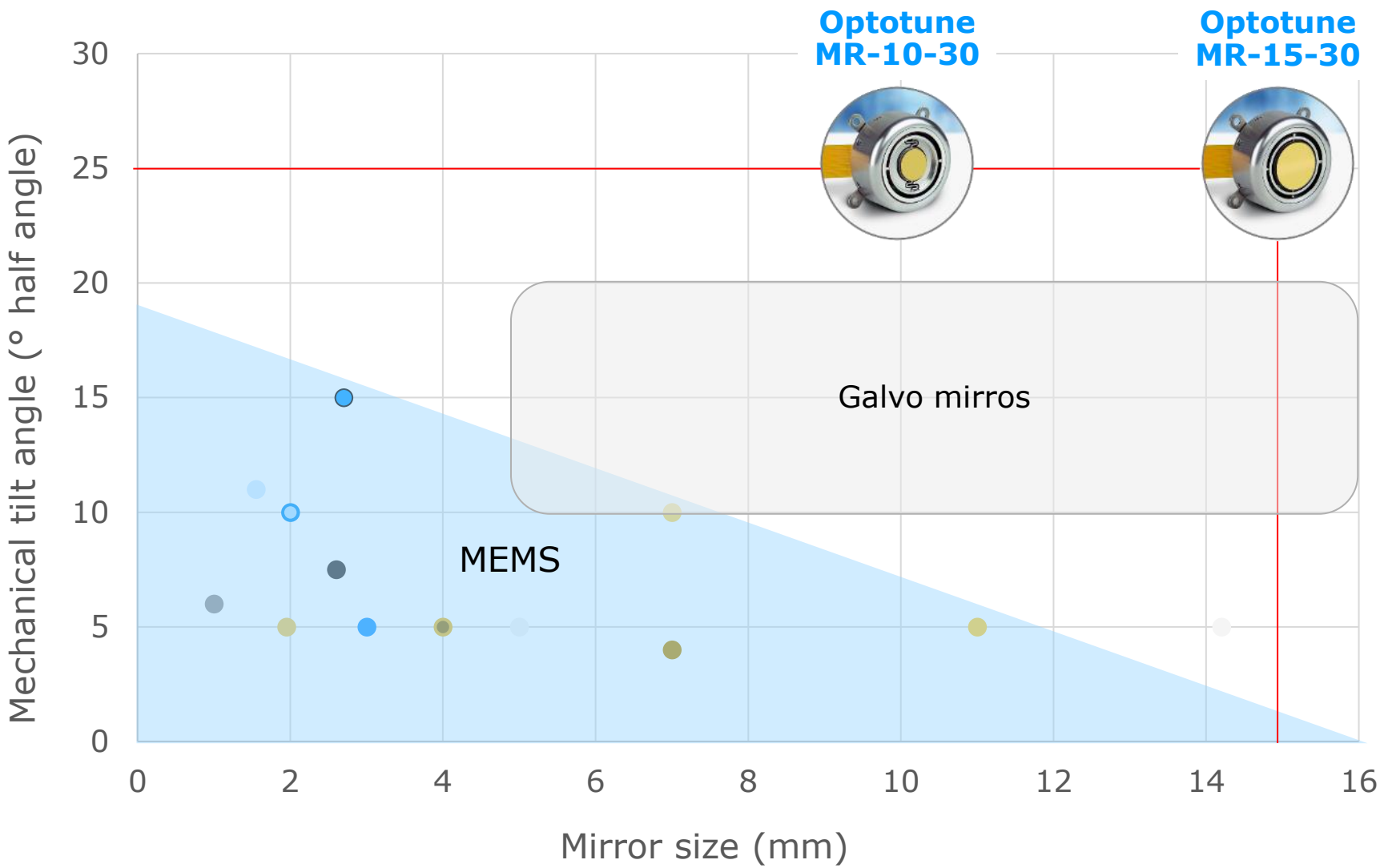
Agenda

- Comparison of scanning technologies
- Mirrors
  - MR-15-30 quasi-static
  - MR-10-30 2-axis resonant
- Drivers
- Applications

Tilt vs Mirror size – competing technologies

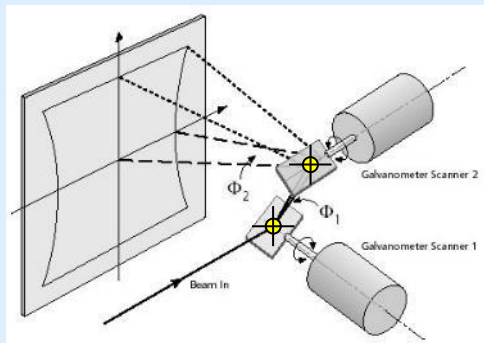
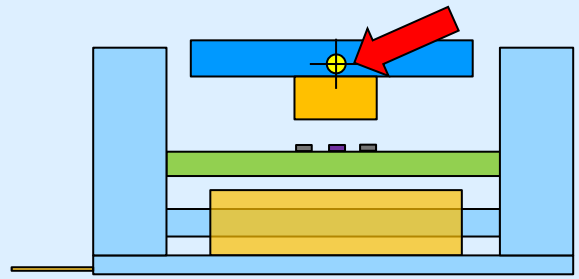
The MR-15-30 has exceptionally large tuning angle and mirror size!



Overview of mirror technology

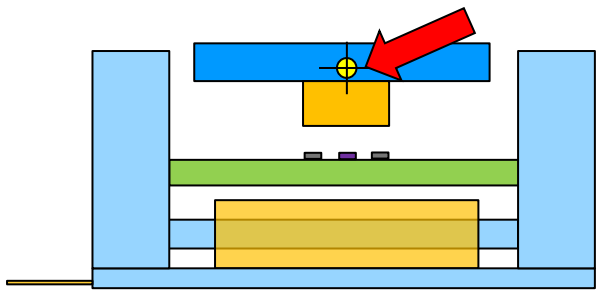
	MEMS	Galvanometer	optotune 
Real 2D	**Yes**	No (2x 1D)	**Yes**
Mirror size	3-7 mm	**5-30 mm**	**15 mm/10 mm**
Package size	**15-30 mm**	60-240 mm	**30 mm**
Mech. half angle	5-11 deg	10 deg	**25 deg**
Repeatability	10-500 microrad	**2-15 microrad**	30-100 microrad
Full stroke frequency	**100-300 Hz**	**300-600 Hz**	20 Hz/**250 Hz**
Beam shift	**No**	Yes (complex calibration required)	**No**
Robustness	++	+++	**+++**
Shock resistance	medium	medium	**high**

Comparison Galvo mirror vs Optotune mirror

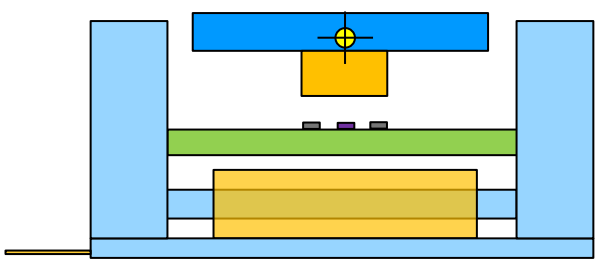
	Galvanometer 	optotune 
Point of rotation	Far away from mirror surface 	Close to mirror surface 
Beam shift	Yes, needs to be corrected in software/calibration	No
Package size	Bulky (2nd mirror needs to be larger) 	Compact
Reflection loss	double	single

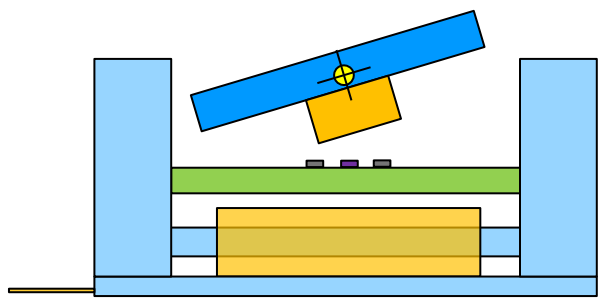
Why the MR-15-30 has good shock & vib properties

- Center of mass = center of rotation → little torque induced by shock & vib



- There is a restoring magnetic force by design





- The base resonance (pendulum) is quite low (17 Hz). It is thus relatively easy to compensate for shock and vibration influence wiht an aggressive PID control.

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- Mirrors
  - MR-15-30 quasi-static
  - MR-10-30 2-axis resonant
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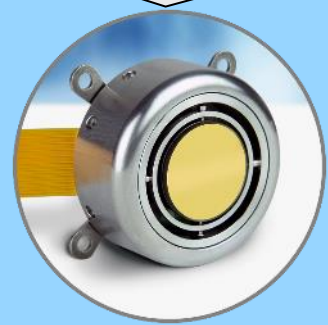
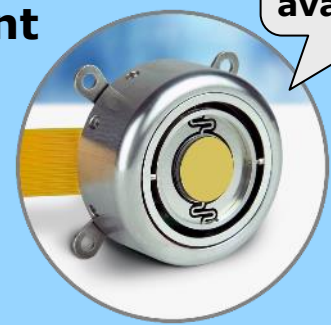
- Applications

Optotune has extended its mirror portfolio

	MR-15-30	MR-10-30 2-axis resonant
	In production 	Engineering samples available 
Mirror size	15 mm	10 mm
Mechanical tilt – fast axis (half angle)	25°	12.5°
Full-scale bandwidth – fast axis	20 Hz	250 Hz
Mechanical tilt – slow axis (half angle)	25°	25°
Full-scale bandwidth – slow axis	20 Hz	20 Hz
Mech. Repeatability RMS typical	30-100 µrad	30-100 µrad (slow axis)
Footprint	30x14.5	30x14.5
Position feedback	yes	yes

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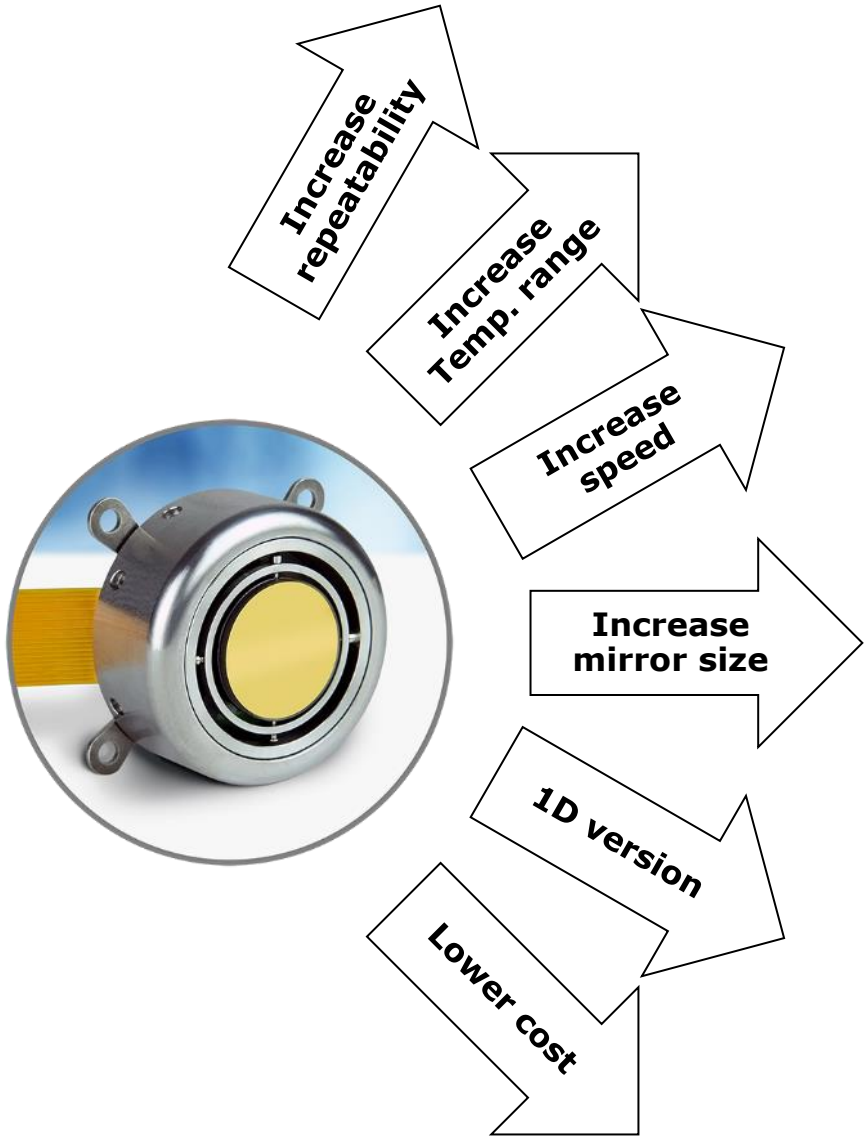
The development continues … tell us what you need!



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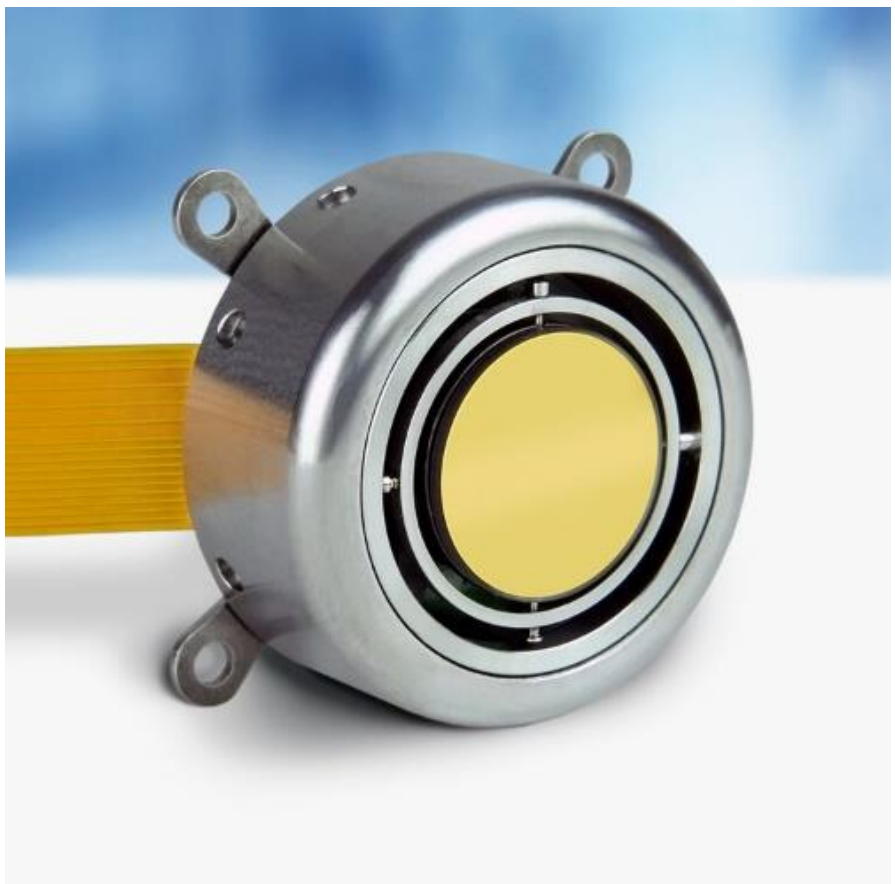
MR-15-30 – ideal for point-and-shoot



Mirror size	15 mm
Mechanical tilt – fast axis (half angle)	25°
Full-scale bandwidth – fast axis	20 Hz
Mechanical tilt – slow axis (half angle)	25°
Full-scale bandwidth – slow axis	20 Hz
Mech. Repeatability RMS typical	30-100 μrad
Footprint	30x14.5
Position feedback	yes

Datasheet

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MR-15-30 specifications

Mechanical specifications[1]

Actuator Type	4-Quadrant (2 axis, bi-directional)		
Mechanical tilt angle DC	±25 X axis; ±25 Y axis (circular FOV)	°	
Mechanical tilt angle dynamic	±25 X axis; ±25 Y axis (circular FOV)	°	
Mirror diameter	15	mm	
Center of rotation to mirror surface	1.3	mm	
Housing diameter	30.0	mm	
Mechanical clamping	4x M2 screws		
Height	14.5	mm	
Weight	29.3	g	
Magnetic shielding	yes		
Zero drift	100	µrad/K	RMS value over entire FOV, typical
Sensor resolution	22	µrad	with 14bit ADC
Repeatability	40	µrad	RMS value over entire FOV, at room temperature
Calibration accuracy	0.25	°	RMS value over entire FOV, factory calibration may degrade to 0.5° (typ. 0.3°) long-term, MR-E-2 interpolates from 50 points
Static displacement constant	3	rad/A	Linearized full range
Angular acceleration constant	1.4 * 10^4	rad/(A s^2)	Linearized full range
Control specs:			
Full scale bandwidth Sine wave (±25°)	20	Hz	

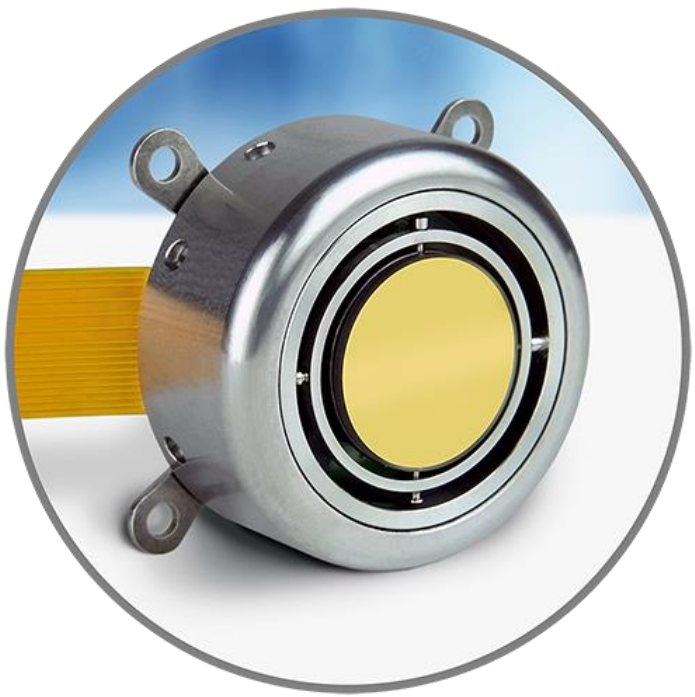
[1] All angles are indicated as mechanical angles

MR-15-30 specifications

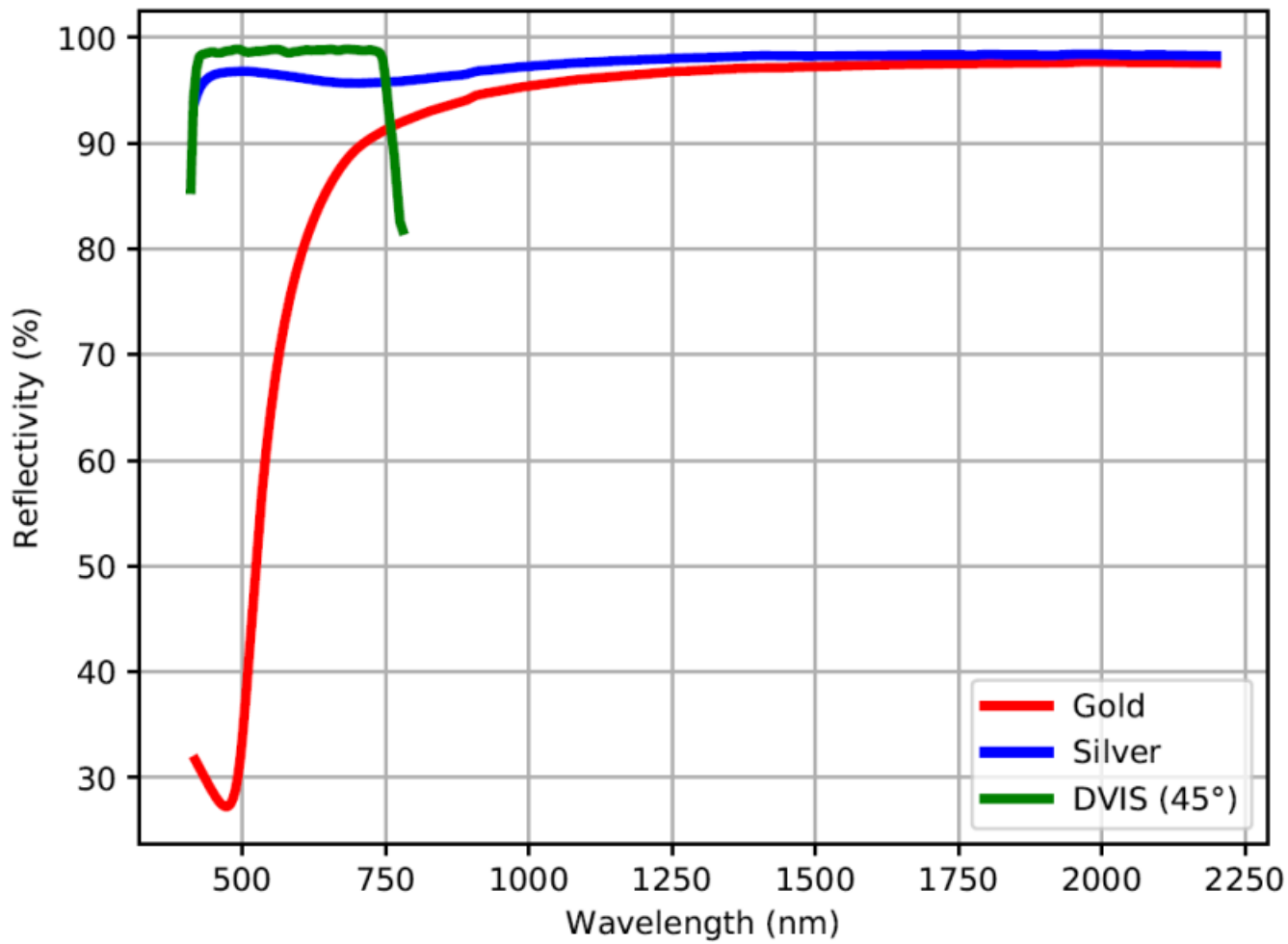
Small signal bandwidth (< ±0.1°)	350	Hz	
Large angle step settling time (20° step)	13	ms	Measured with MR-E-2 driver board with 700mA peak current
Small angle step settling time (0.1° step)	3	ms	Measured with MR-E-2 driver board with 700mA peak current
Optical specifications			
Surface finish	Protected gold, protected silver and dielectric (VIS), other custom coatings available		
Reflectivity Protected Gold Protected Silver Dielectric VIS	Average >95% (800 nm < λ < 2 µm) >96% (450 nm < λ < 2 µm) >97% (450 nm < λ < 650 nm)		 45° AOI 45° AOI 45° ± 25° AOI
Surface quality	5/ 5x0.4; L1x0.06; C3x0.25; E 0.25		ISO 10110 (60-40 Scratch-Dig)
Mirror flatness	λ/2	@549nm (ISO Norm 10110)	
Electrical specifications			
Control interface	Analog interface for driver coils and for feedback readout		
Max continuous current (RMS)	0.3	A	Per coil. See thermal management
Peak current	2	A	For 10 ms duration
Max mean actuation power	1.5	W	Both coils together
Coil resistance	11	Ohm	Typical
Coil inductivity	6	mH	Typical
Position sensor supply current (@1.5V)	40	mA	
Position sensor output current	0.1	mA	4 channels, typical
Temperature sensor	LM75B or equivalent		I2C-Address: 0x48 (+R/W bit)
EEPROM[2]	M24C08 or equivalent		I2C-Addresses: 0x50 to 0x53 (+R/W bit)
Environmental specifications			
Operating temperature	-20 to +85	°C	for higher temp. ranges contact Optotune
Storage temperature	-40 to +85	°C	for higher temp. ranges contact Optotune
Shock	105 *g*, 15 ms		DIN EN 60068-2-27
Vibration	2 *g*, 10-150 Hz		ISO 9022-3-36
Cycle life	>10^9	cycles	

[1] Despite the protective coating layer, it is best to avoid exposing silver mirrors to high humidity environments due to the associated tarnishing risk.

MR-15-30 in action



Reflection spectra



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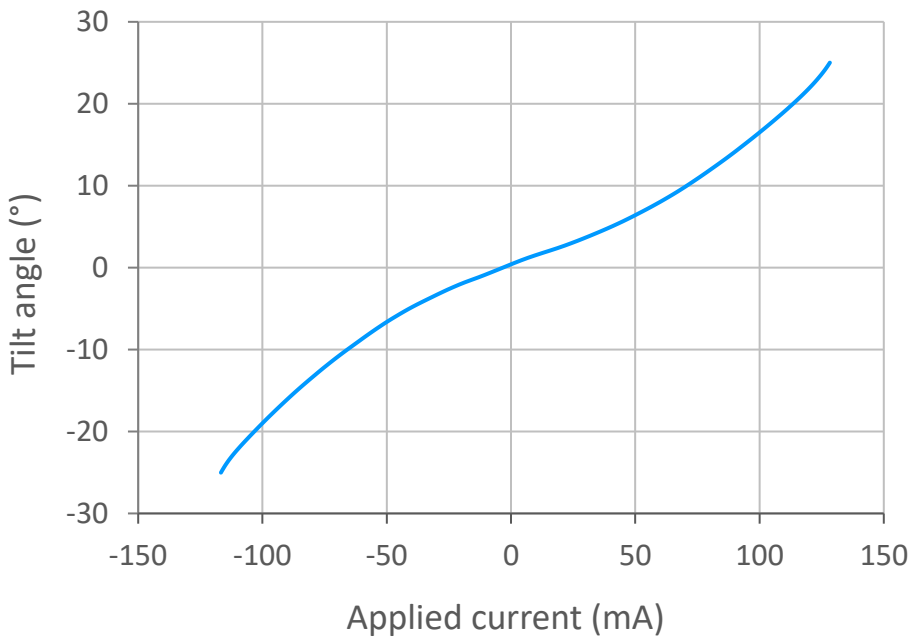
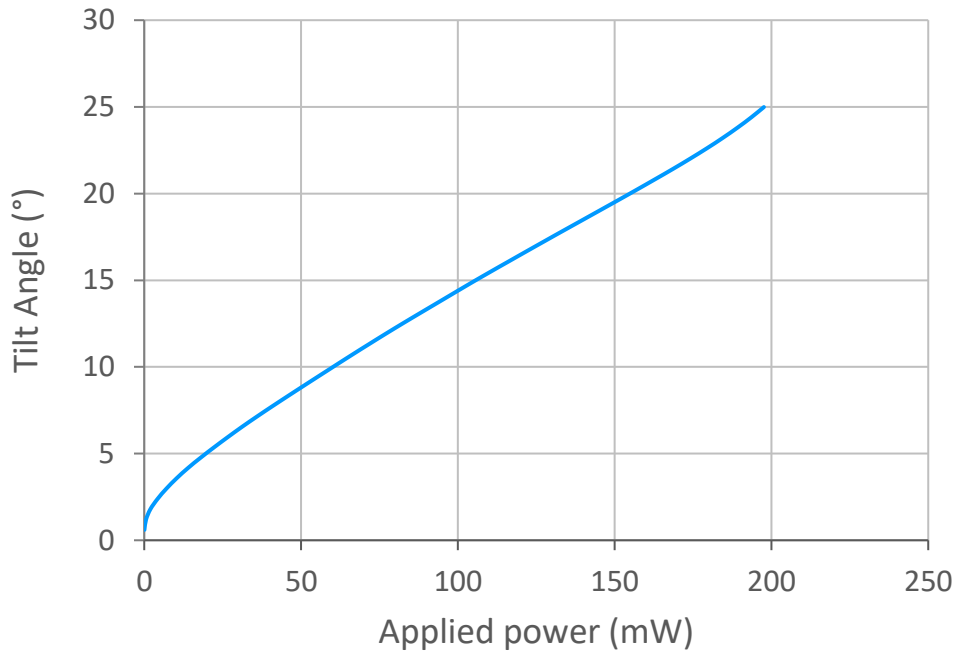
MR-15-30 – static response

Current vs Angle



Power vs Angle



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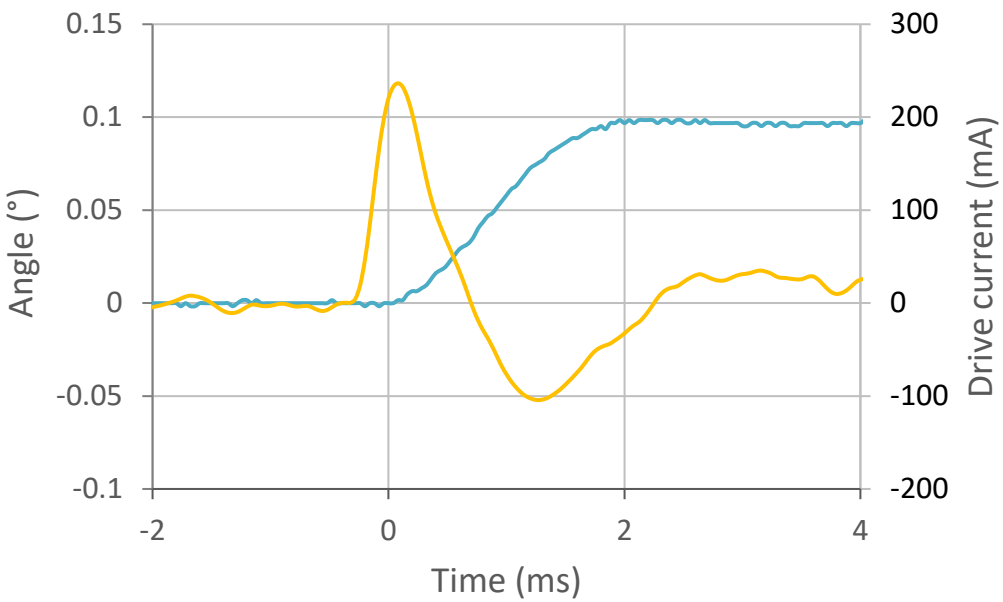
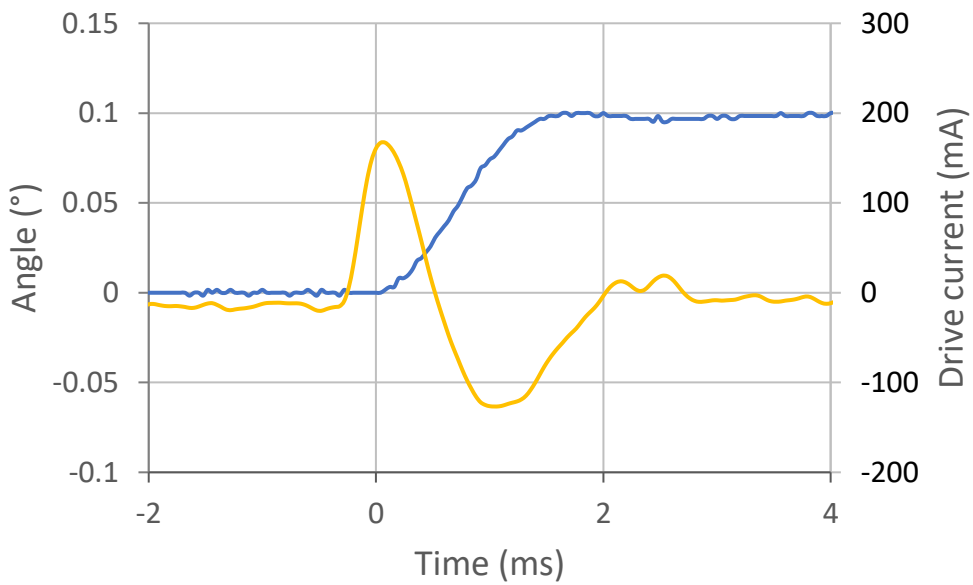
MR-15-30 – small step response (0.1° step)

Outer axis



- Step response < 1.4 ms

Inner axis



- Step response < 1 ms

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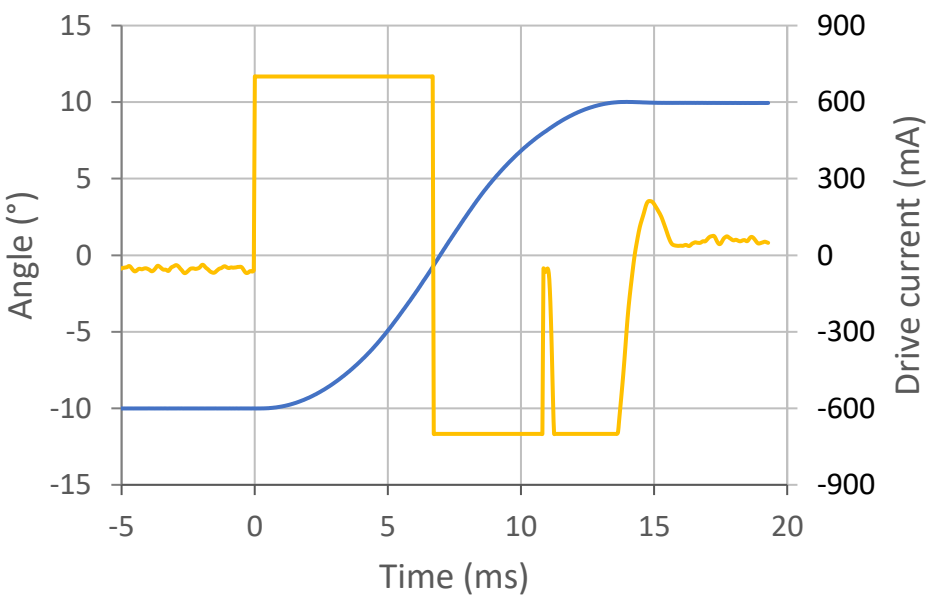
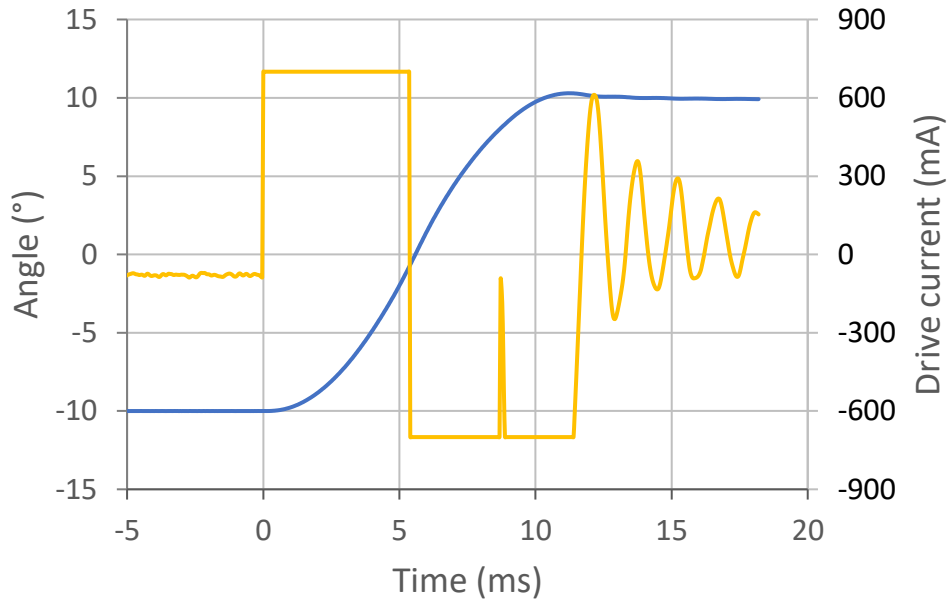
MR-15-30 – Large step response (20° step)

Outer axis



- Large step response < 7.5ms

Inner axis



- Large step response < 6.2ms

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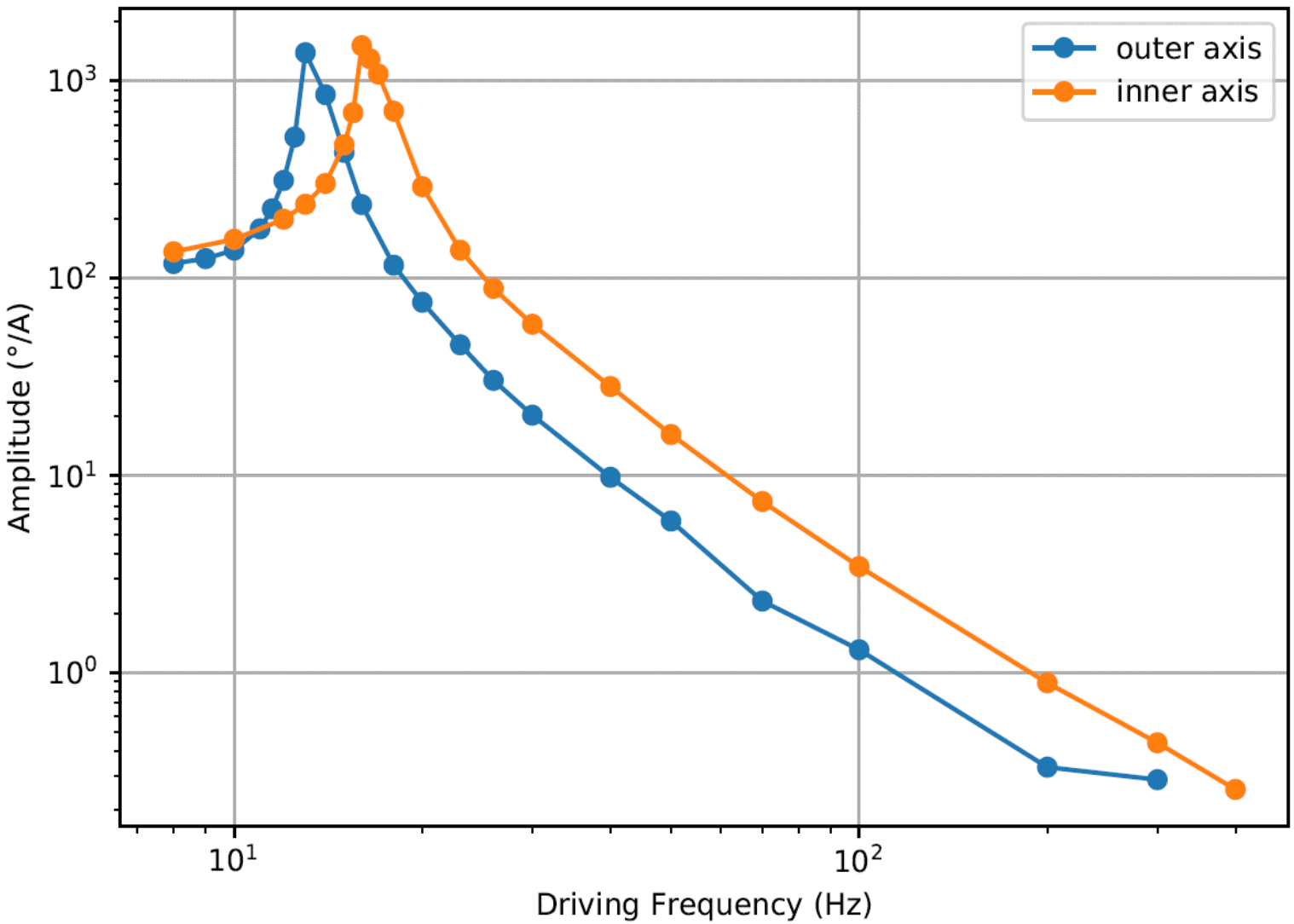
Magnitude response



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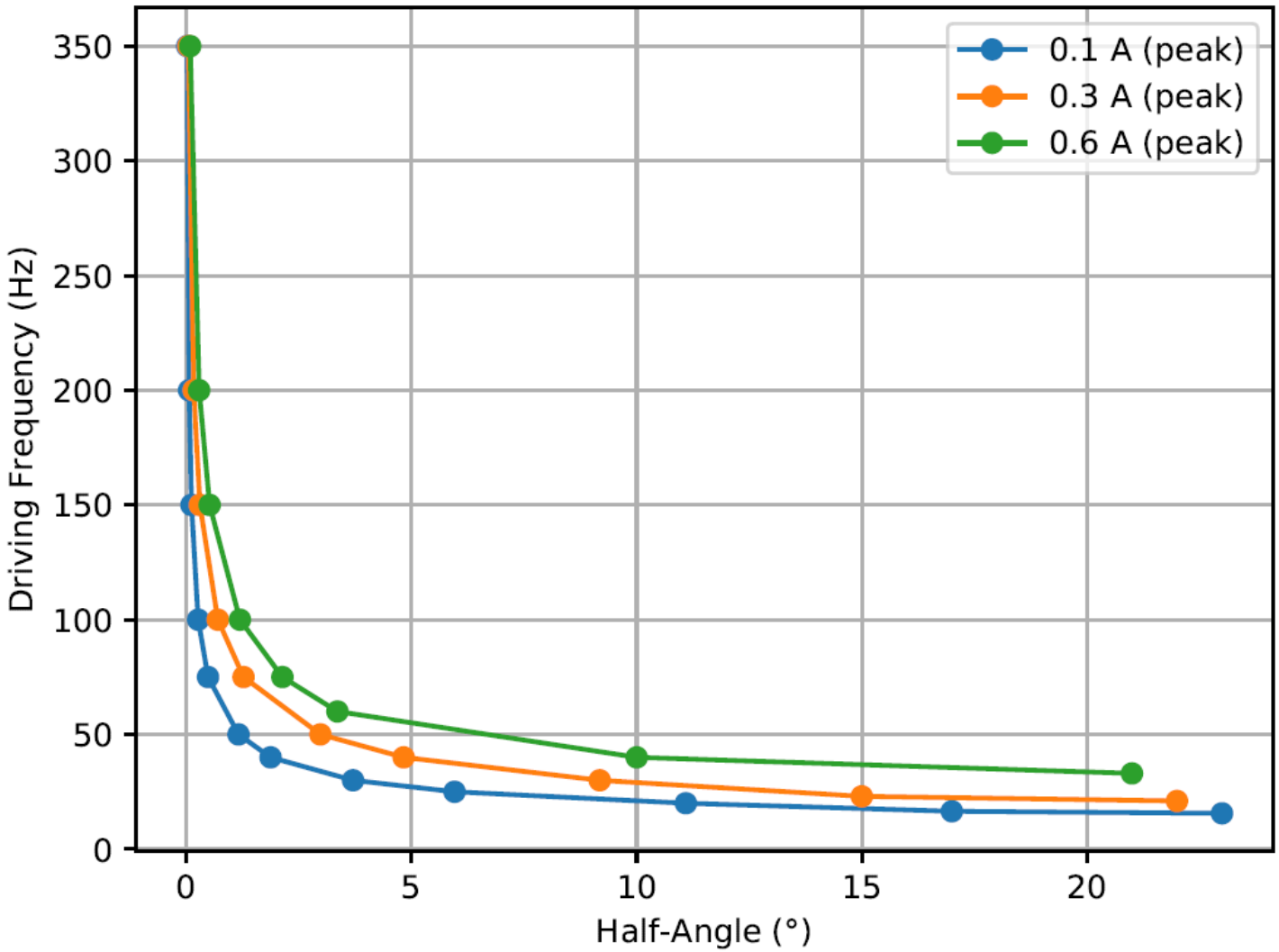
MR-15-30 – Speed sine wave



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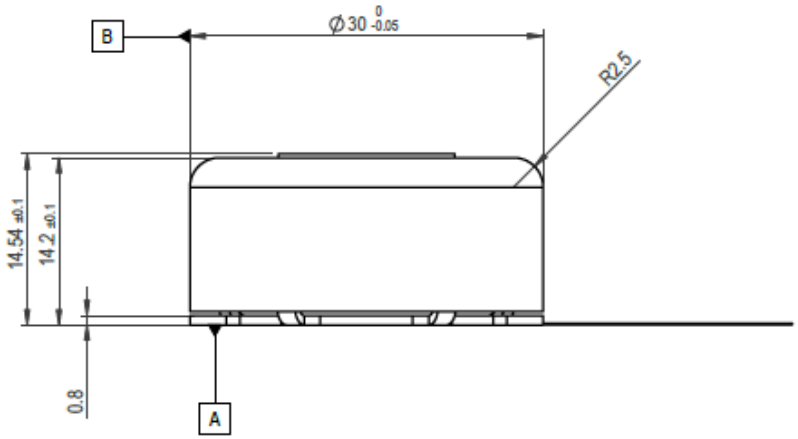
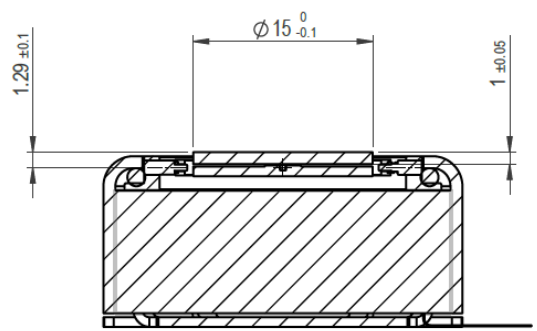
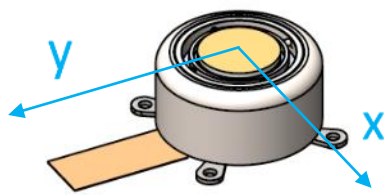
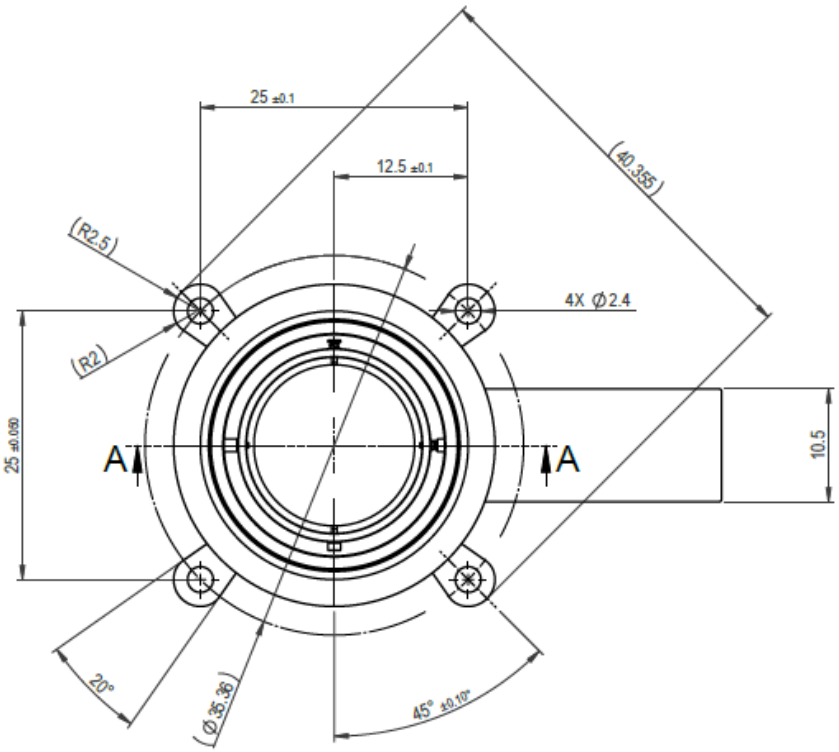
Mechanical drawing of MR-15-30









A-A

Mechanical play of Gimbal:
Lateral 7-12 µm
Axial: preloaded.

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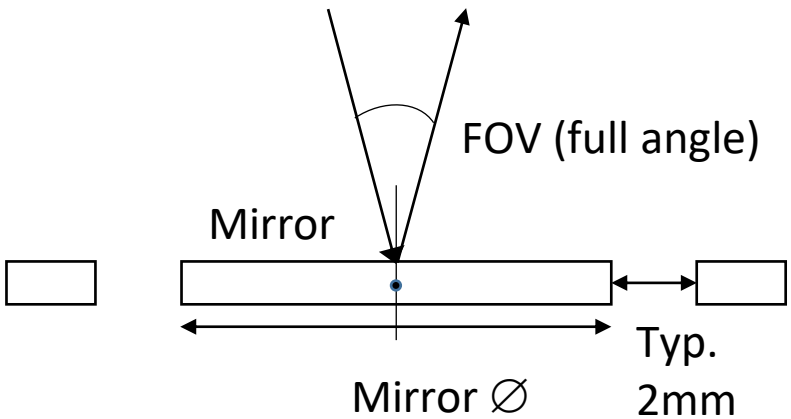
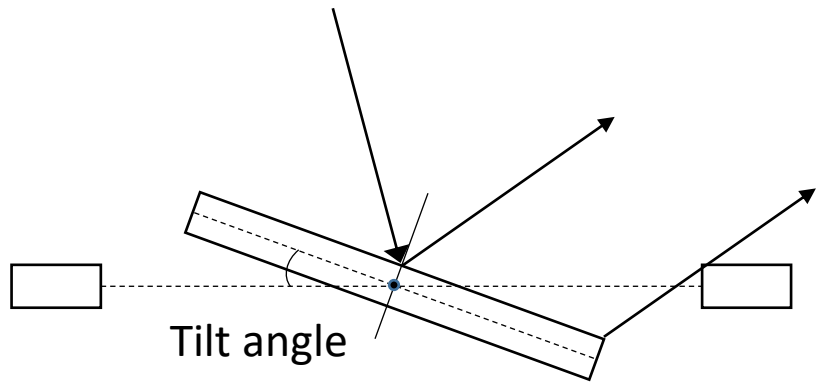
MR-15-30 – electrical pin-out

Pin	Function	Value	Pin	Function	Value
1	Position feedback supply Cathode	40 mA 1.5 V	11	VDD	3.3V
2	Position feedback supply Anode		12	SCL	Digital 3.3 V
3	Y Coil +	± 1 A ± 15 V	13	SDA	Digital 3.3 V
4			14	GND	
5	Y Coil -		15	Position feedback Anode	currents (µA range)
6			16	Position feedback Y2 Cathode	
7	X Coil +		17	Position feedback Y1 Cathode	
8			18	Position feedback X2 Cathode	
9	X Coil -		19	Position feedback X1 Cathode	
10			20	Position feedback Anode	

MR-15-30 – Beam clipping

- Clipping of beam depends on beam diameter and tilt angle





- By request, Optotune can supply an EXCEL based calculation tool to evaluate beam clipping

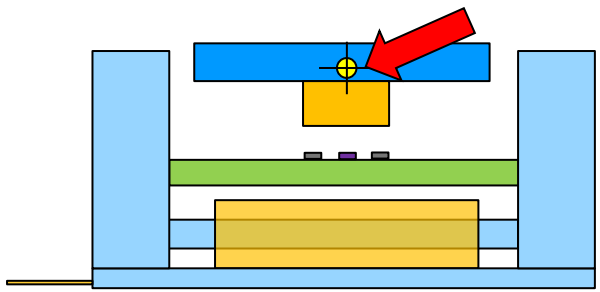
The MR-15-30 has gone through environmental testing

- The MR-15-30 is going through environmental and accelerated aging tests as outline below:

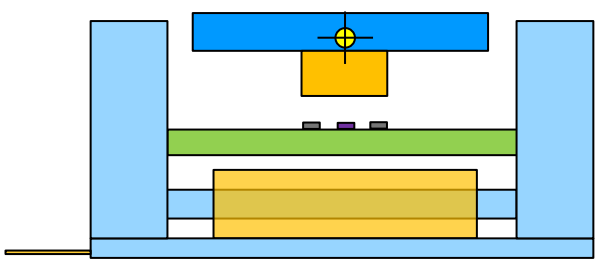
Test	MR-15-30
Mechanical cycling: Cycling test (on-going): 1 billion cycles reached on December 31st 2019 with no signs of fatigue.	On-going
Temperature cycling – non-operational 85°C/60h, -40°/60h; 2 cycles, non-operational. No significant change in repeatability	Passed
Temperature cycling –operational -20°C ... 90°C operational (steady state jumps over entire FOV every 5sec, 20 cycles 60hours)	Passed
Temperature drift & heating effects Temperature drift: approx. 20urad/K No significant self-heating at low frequency	Passed
Temperature & Humidity 85°C / 85% (duration: 1 week)	Passed
Shock test According to DIN EN 60068-2-27, 15 ms deceleration, three drops per axis. Mirror is not affected by shocks up to 105 g.	Passed
Vibration tests According to ISO 9022-3-36-03-01, 2 g, 10-150 Hz	Passed

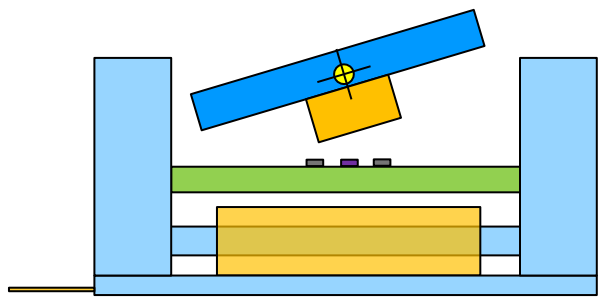
Why the MR-15-30 has good shock & vib properties

- Center of mass = center of rotation → little torque induced by shock & vib



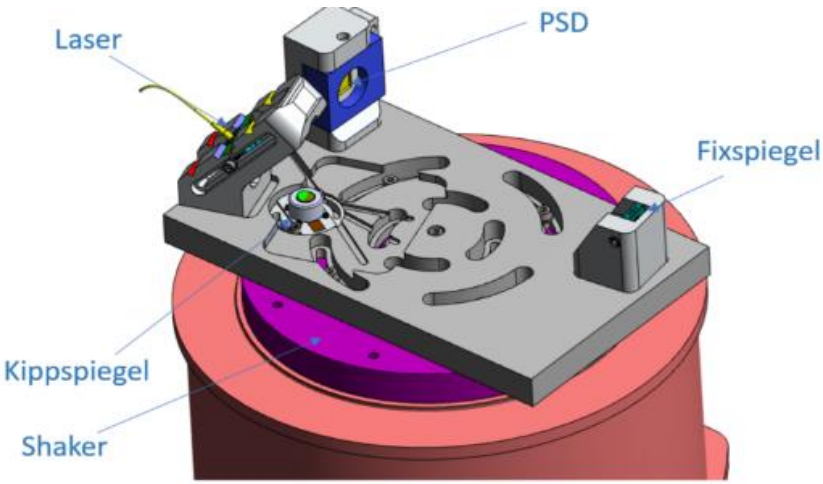
- There is a restoring magnetic force by design





- The base resonance (pendulum) is quite low (17 Hz). It is thus relatively easy to compensate for shock and vibration influence with an aggressive PID control.

The MR-15-30 shows good pointing accuracy under vibration

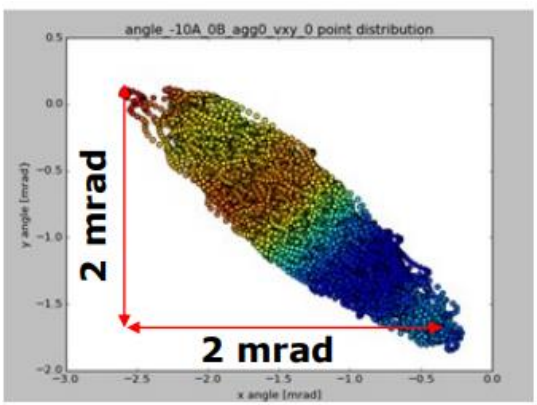


Random vibration
5Hz – 2kHz
RMS 30.8m/s^2

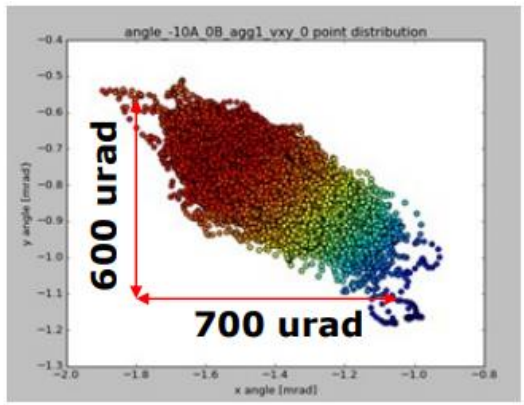
Table 60: Test parameters, wide-band random vibration for sprung masses

Vibration excitation	Wide-band random vibration	
Test duration for each spatial axis	8 h	
RMS value of acceleration	30,8 m/s²	
Vibration profile Figure 30	Frequency in Hz	Power density spectrum in (m/s²)²/Hz
	5	0,884
	10	20
	55	6,5
	180	0,25
	300	0,25
	360	0,14
	1 000	0,14
	2 000	0,14

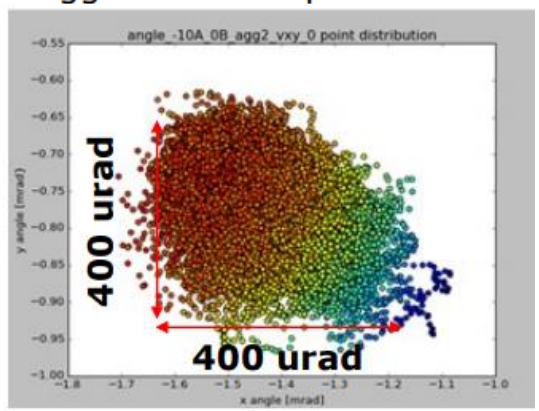
Lax PID parameters:



Medium PID parameters:



Aggressive PID parameters:



Intrinsic setup
Resolution:
300 µrad

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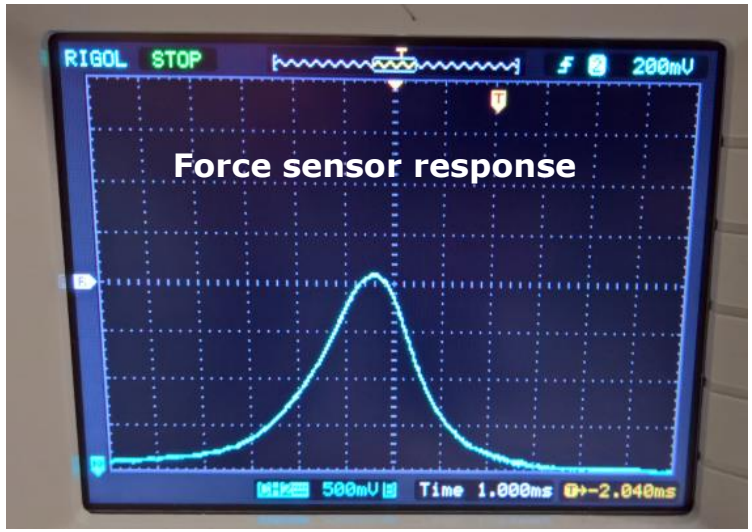
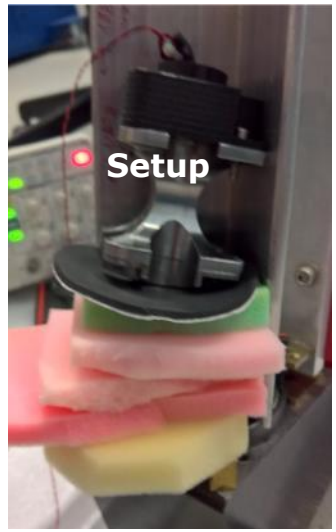
The MR-15-30 maintains its performance up to 200G (automotive spec: 50G)

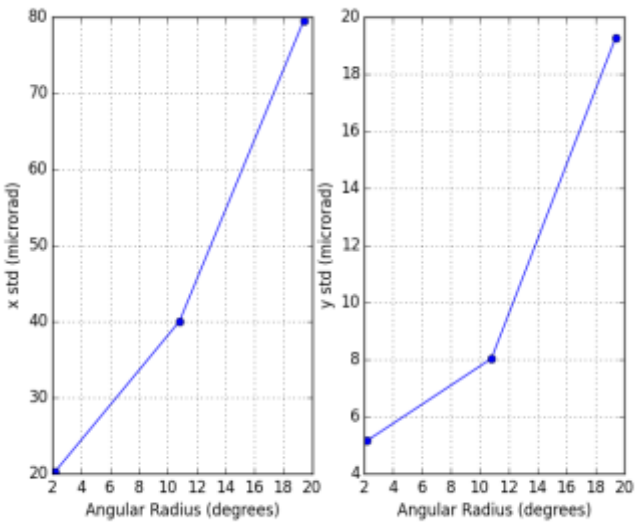
Table 62: Test parameters, M-05 Mechanical shock

DUT operating mode	If the component is operated with operating load during driving operation: II.c in the "driving operation" operating situation If the component is not operated with operating load during driving operation: II.a
Peak acceleration	500 m/s^2
Shock duration	6 ms
Shock form	Half-sine
Number of shocks per direction (±X, ±Y, ±Z)	10
Number of DUTs	6

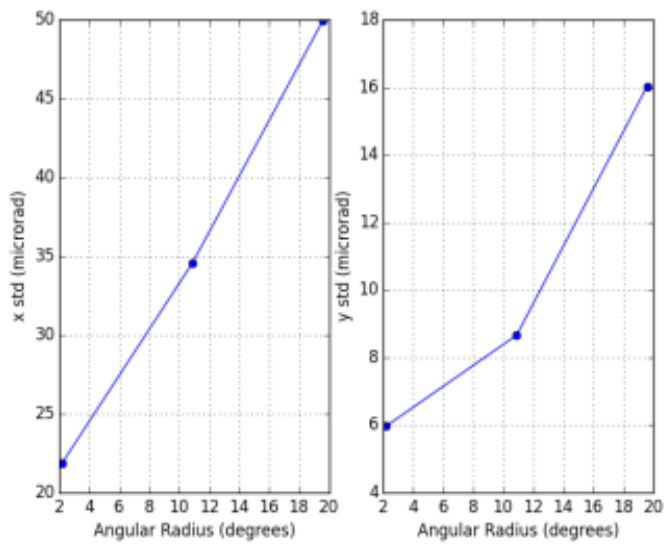




Before shock



After 200 G shock



Structural damage occurred only at 1'000 G

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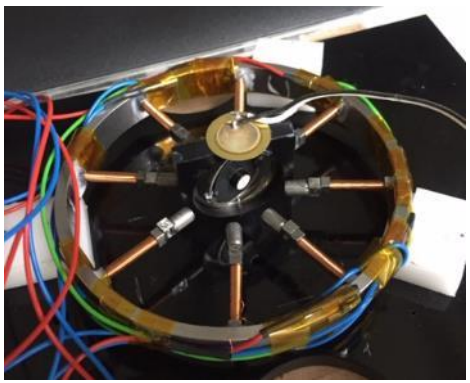
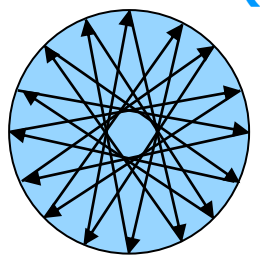
On-going lifetime tests

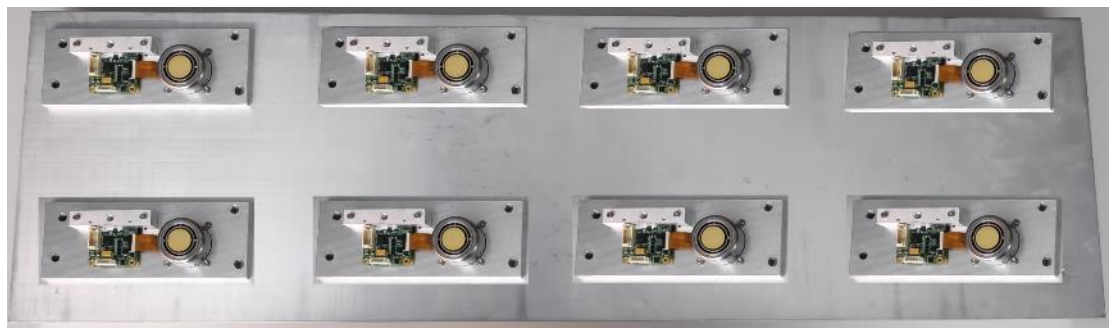
Accelerated reliability test of gimbal only





- Up to 10k rpm, incl. vibration sensor
- Tested the gimbal with billions of cycles

Complete mirror reliability test (mirror + driver)

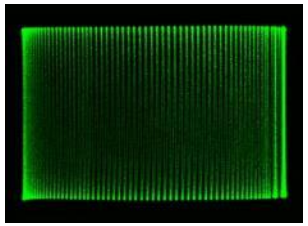


- 20 mirrors running-non-stop
- Lifetime test of the complete mirror incl. driver for a full year

Agenda

- Comparison of scanning technologies
- Mirrors
  - MR-15-30 quasi-static
  - MR-10-30 2-axis resonant
- Drivers
- Applications

MR-10-30 – ideal for raster-scans



Mirror size	10 mm
Mechanical tilt – fast axis (half angle)	12.5°
Full-scale bandwidth – fast axis	250 Hz
Mechanical tilt – slow axis (half angle)	25°
Full-scale bandwidth – slow axis	20 Hz
Mech. Repeatability RMS typical	30-100 µrad (slow axis)
Footprint	30x14.5
Position feedback	yes

Configuration	Coating
MR-10-30-G-2 axis resonant	gold
MR-10-30-PS-2 axis resonant	Protected silver

Datasheet

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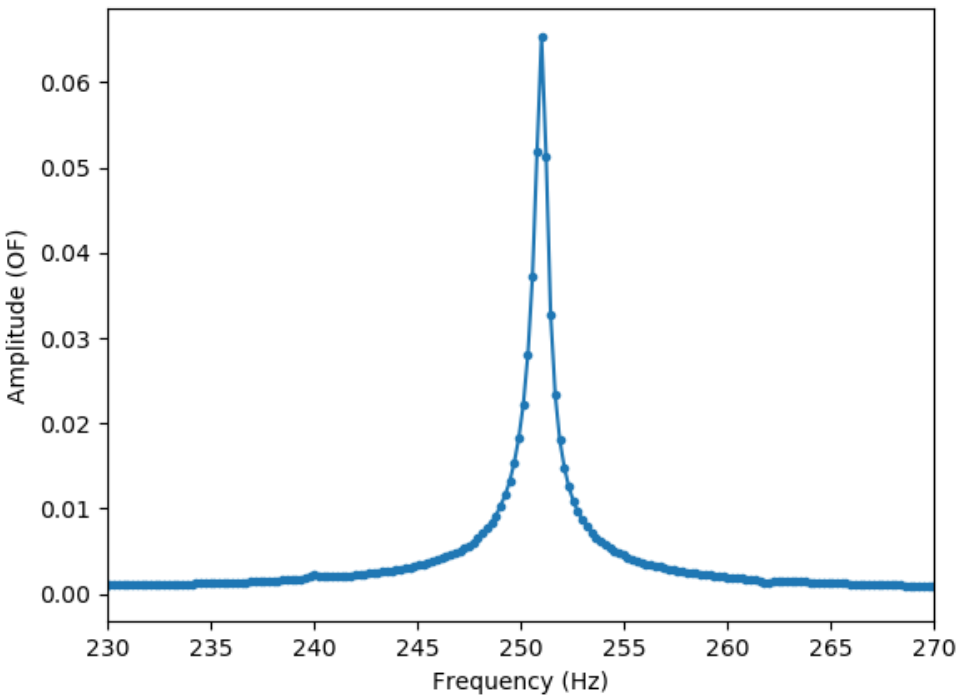
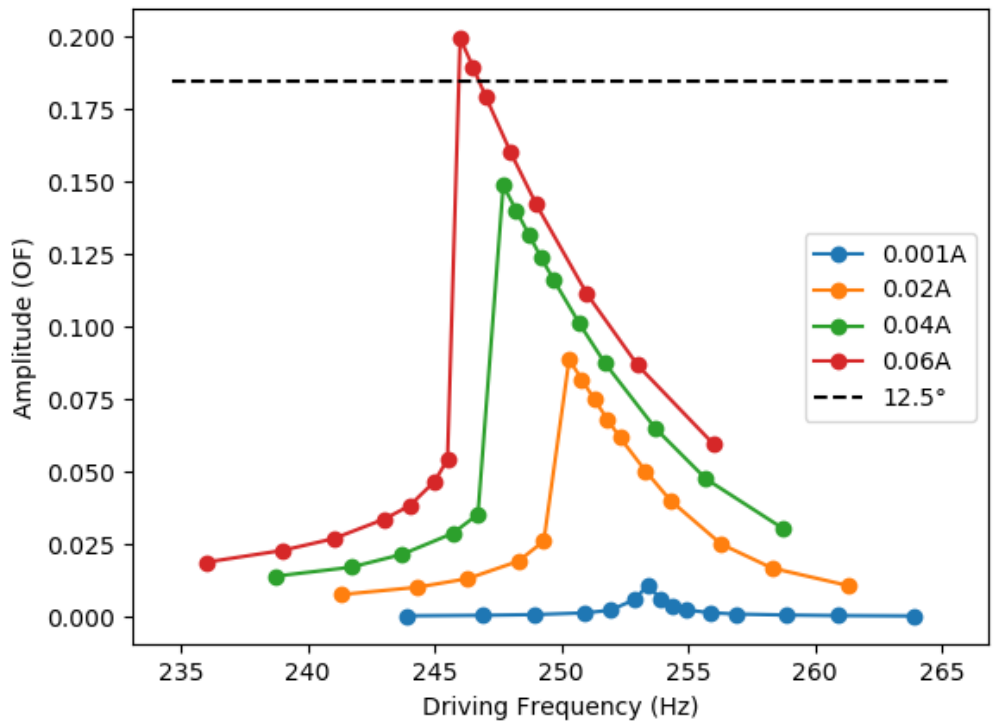
MR-10-30 dynamic response



Ringdown spectrum of the resonant axis



Typical response of resonant axis with sinusoidal excitation and different driving currents. The dashed black line corresponds to the specified maximum range of ±12.5°.

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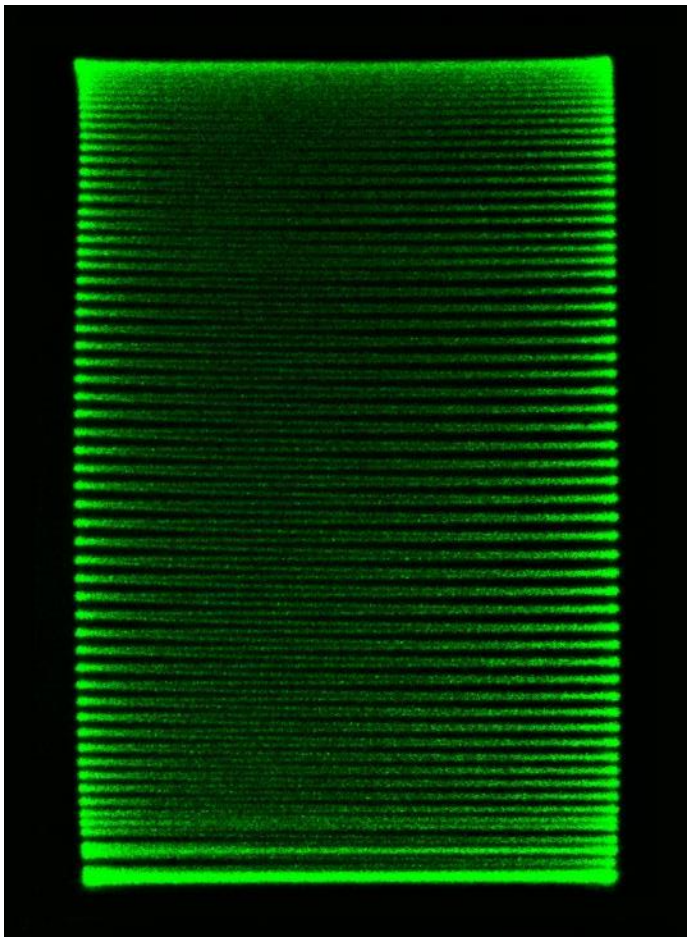
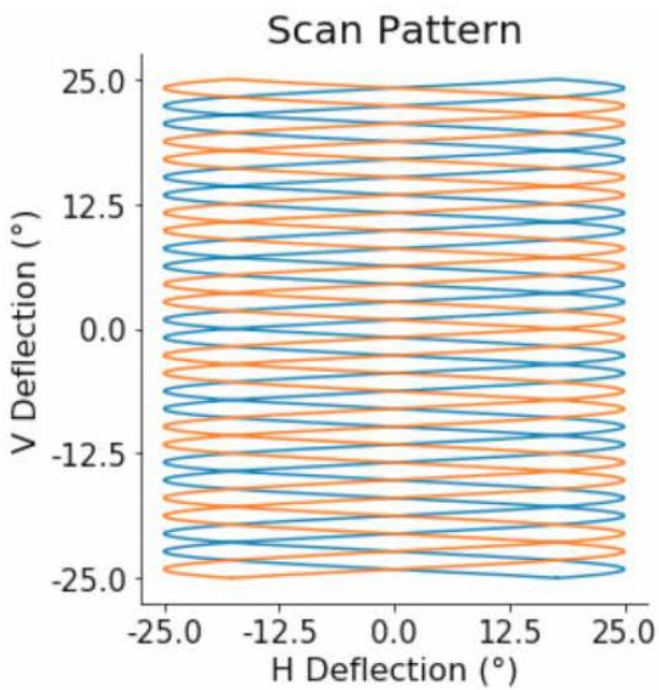
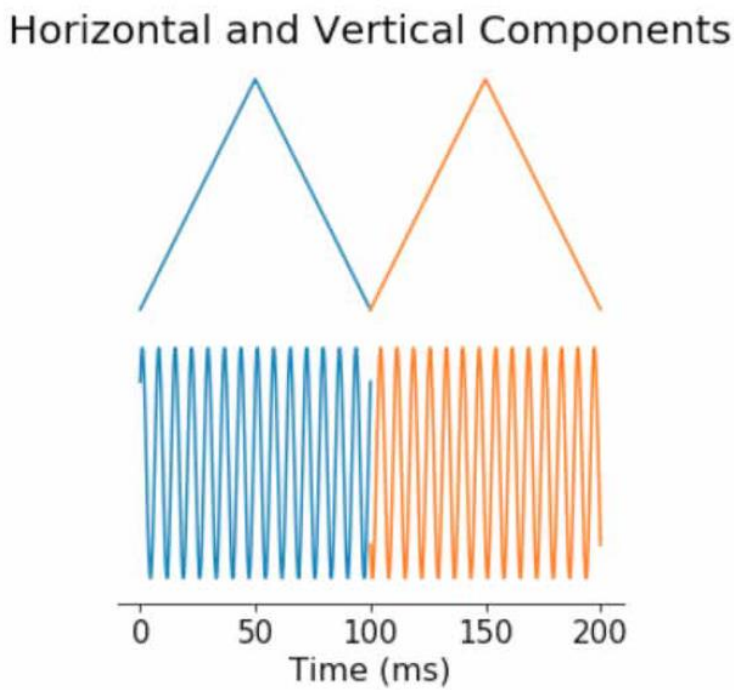
MR-10-30 is designed for raster scanning







Resonant axis: 280 Hz, sine wave, open loop
Non-resonant axis: 10 Hz, triangular wave, closed loop (OF)

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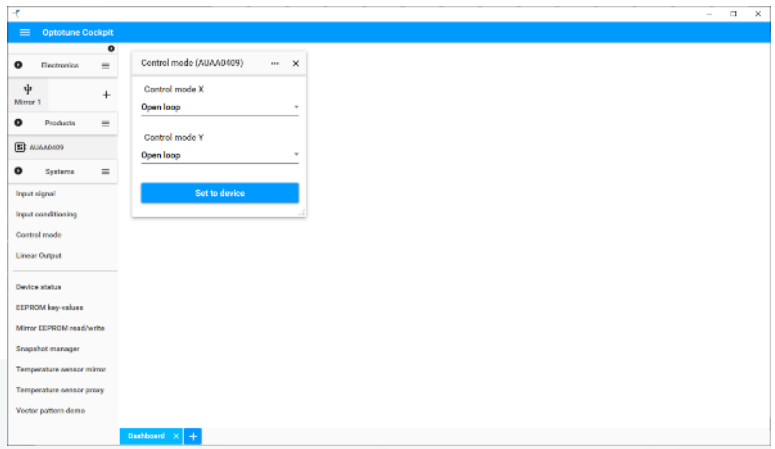
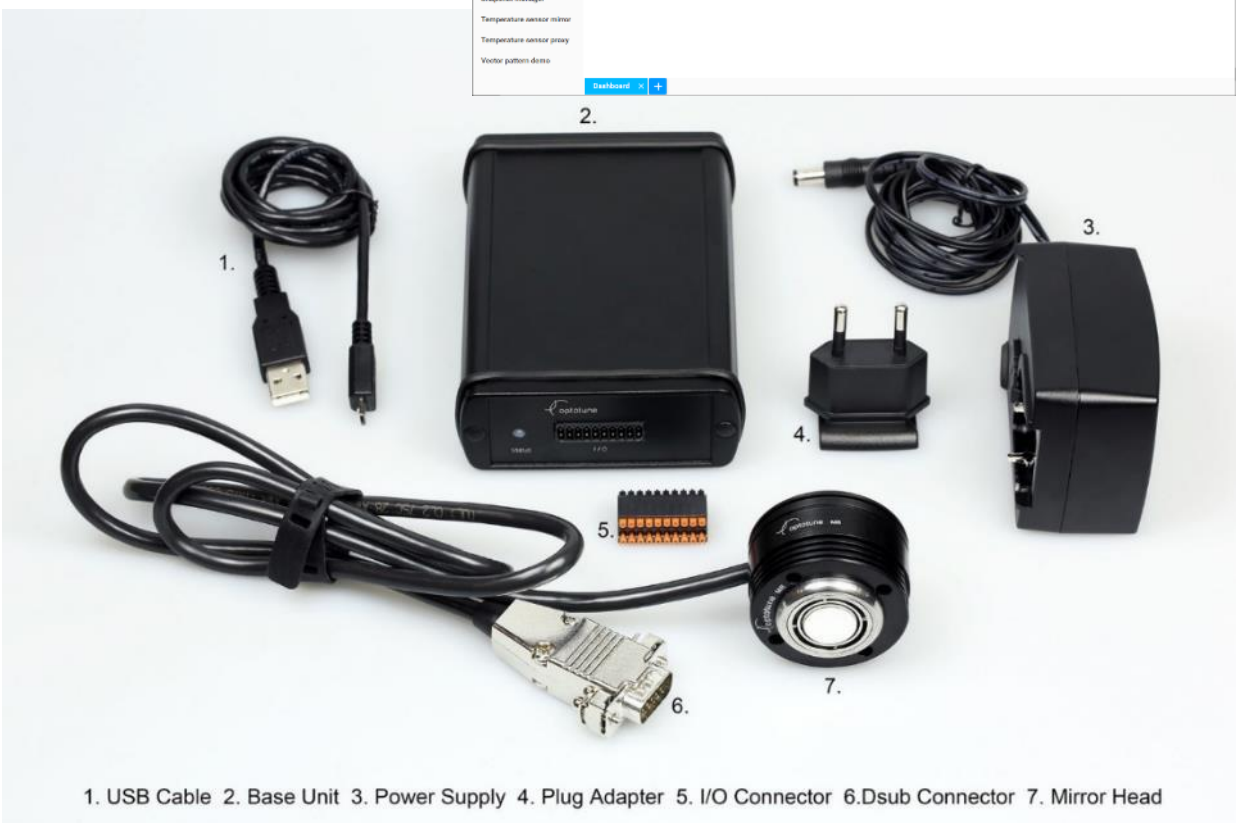
Agenda

- Comparison of scanning technologies
- Mirrors
  - MR-15-30 quasi-static
  - MR-10-30 2-axis resonant
- Drivers
- Applications

Optotune offers complete development kit … (MR-E-2)





1. USB Cable 2. Base Unit 3. Power Supply 4. Plug Adapter 5. I/O Connector 6.Dsub Connector 7. Mirror Head

Graphic user interface *Optotune Cockpit* for control via USB

- Communication interfaces:
  - USB, UART
  - SPI (I2C available on request)
  - Analog input (± 5 V)
- Software SDKs for Python and C# available.
- Electrical specs:
  - 2 channels with closed loop control
  - 700 mA max current
  - 14-bit resolution
  - 10 kHz control loop frequency

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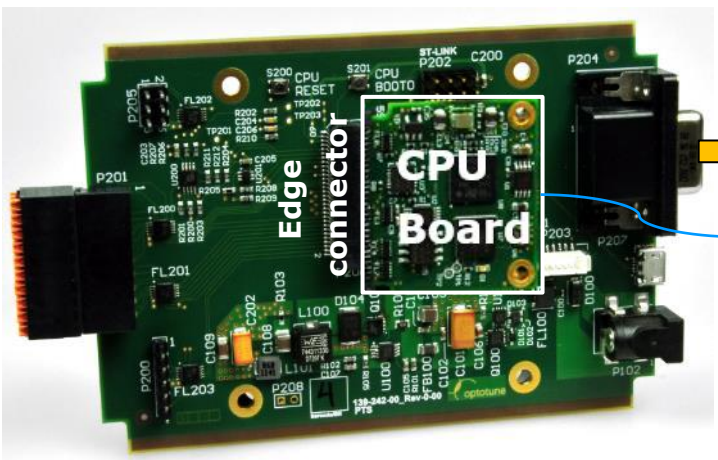
… as well as a compact OEM driver

Modular approach with 3 separate boards

- Proxy board + CPU board = high volume OEM solution
- Proxy board + CPU board + Carrier board
  = evaluation driving electronics / low volume OEM solution
- Interfaces: USB, analog, SPI

Carrier board

schematics of carrier board for free
→ easy integration



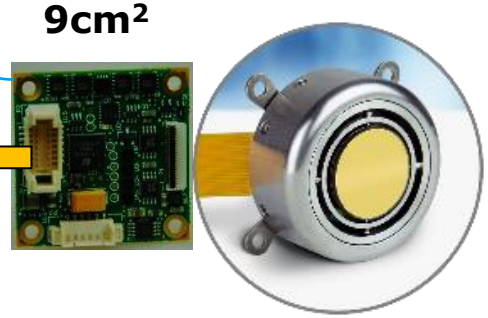
CPU board

- **Digital signal processing**
- **9cm²**

Few m

Proxy Board

- **Current sources**
- **Position feedback**
- **9cm²**



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MR-E-2 Dev Kit

MR-E-2 Base unit

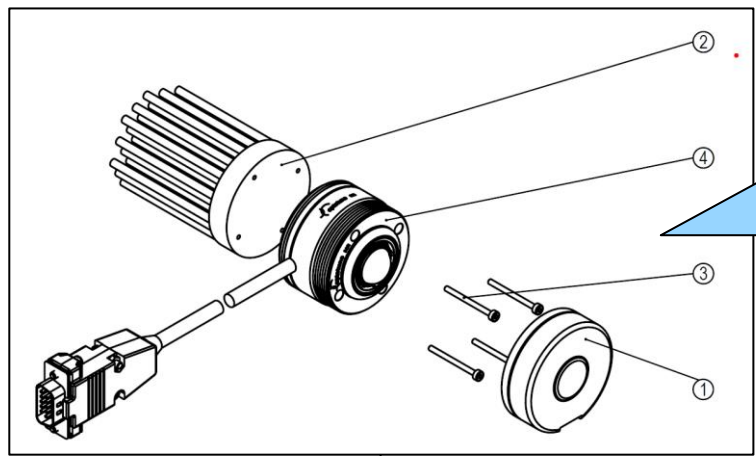
MR-E-2 Base unit controller box

Connector block

Power supply

USB cable

MR-E-2 Head unit



Incl. protective cover & heatsink

Gold
(w. MR-15-30-G)

Silver
(w. MR-15-30-PS)

Dielectric
(w. MR-15-30-DVIS)

Custom
(w. custom coating, resonant mirror MR-10-30, ….)

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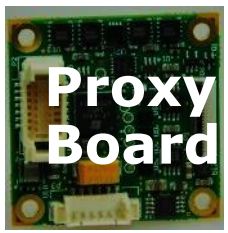
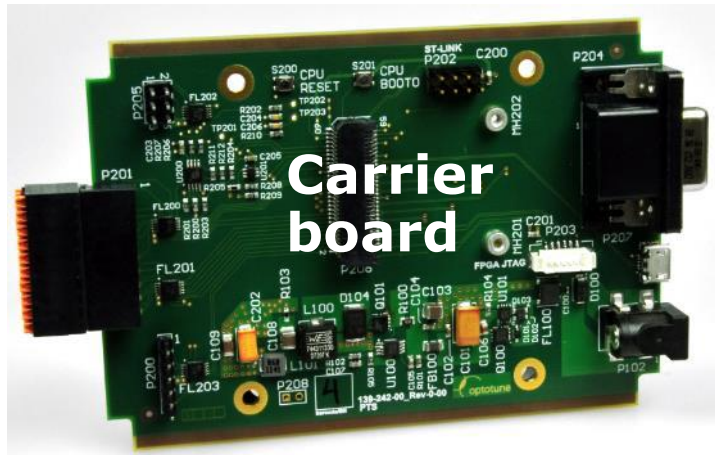
MR-E-2 OEM version

MR-E-2 OEM version





MR-E-2 carrier to proxy board cable assembly

USB cable

MR-E-2 power supply

[Datasheet]

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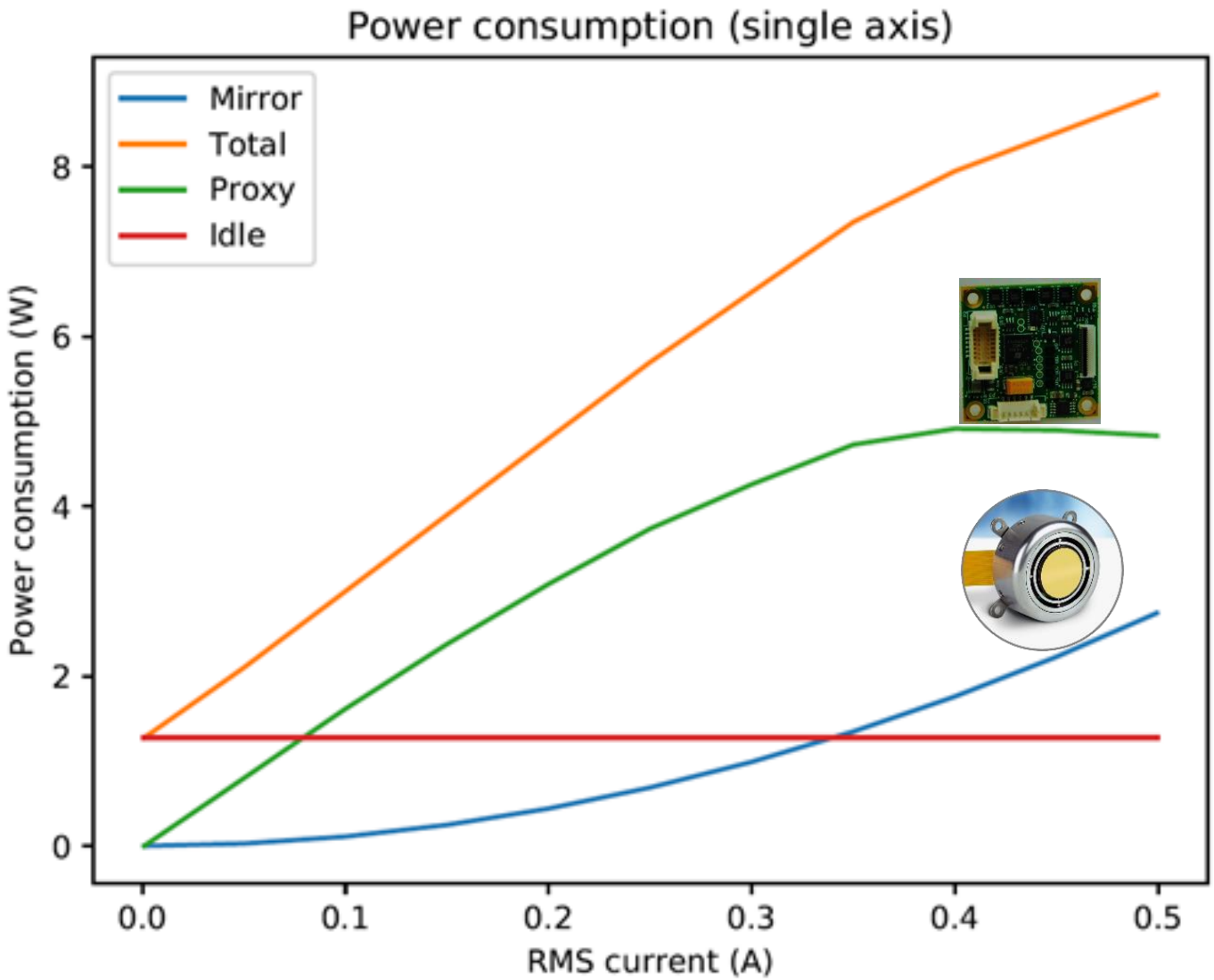
Power consumption mirror head



Agenda

- Comparison of scanning technologies
- Mirrors
  - MR-15-30 quasi-static
  - MR-10-30 2-axis resonant
- Drivers
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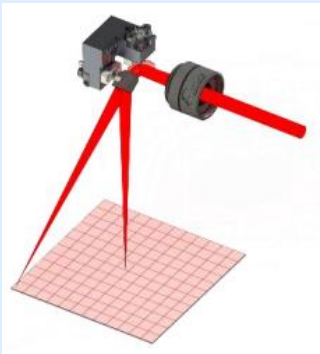
Key applications areas for 2D mirror

3D Printing



Automotive

LiDAR
Dynamic headlights
ADAS (e.g. passenger tracking)

Vision

FOV expansion/zoom
Iris scanner
Eye-tracking
Surveillance (face identification)

Signage

Project simple pictograms
Lasershows

Biomedical

Confocal imaging
Widefield OCT

Metrology

Laser-templating
3D metrology/triangulation
Object detection

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Vision applications

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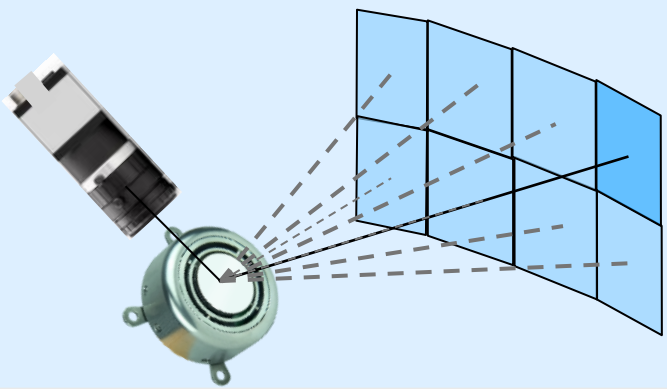
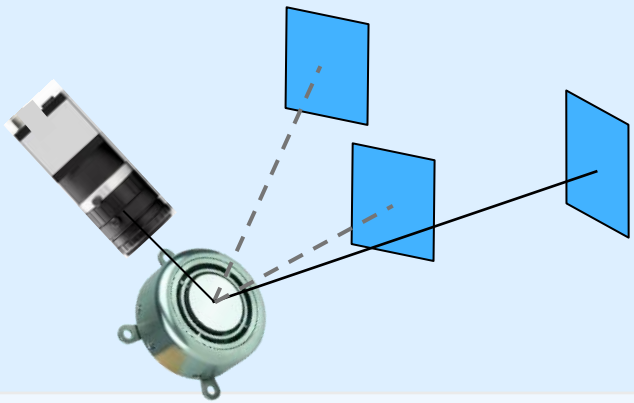
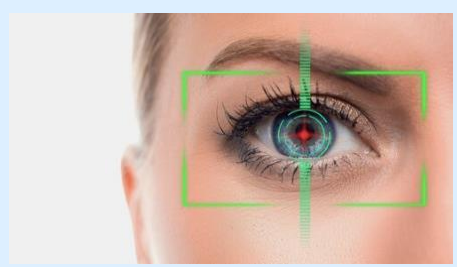
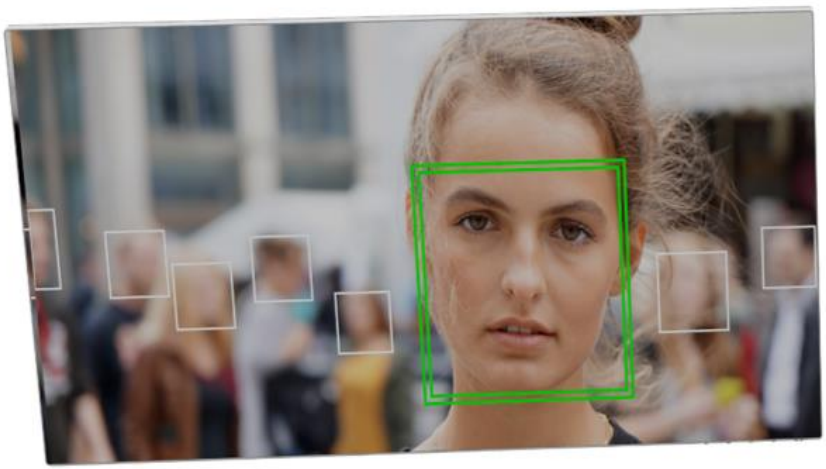
The MR-15-30 has 2 main applications in Vision

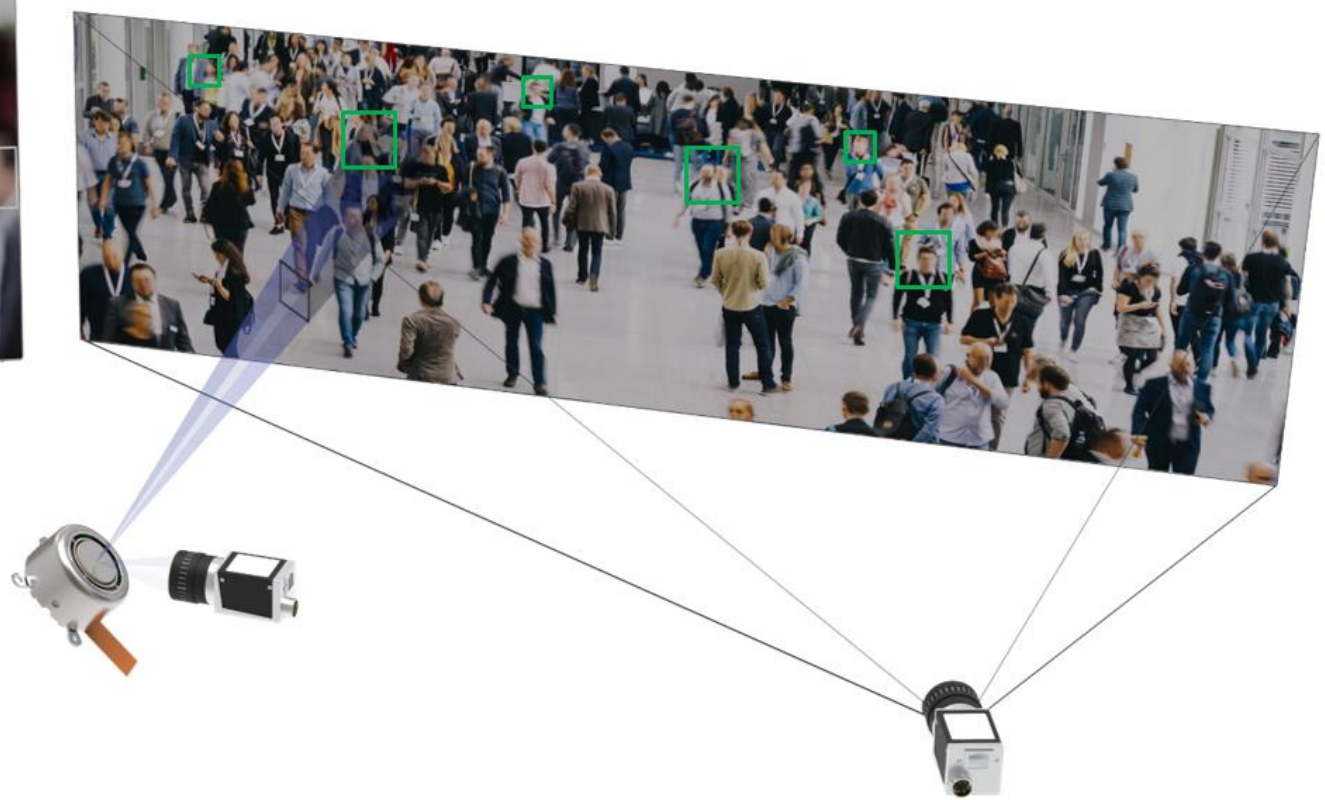
FOV Expansion	AOI Selection
	

• High resolution image with 'normal' image sensor	• Ideal for imaging a small AOI when the exact position is not known, e.g.
	  • Eye-tracking on distance of a few meters (gaming console)
	  • Iris scanning

Surveillance: MR-15-30 for selecting AOI





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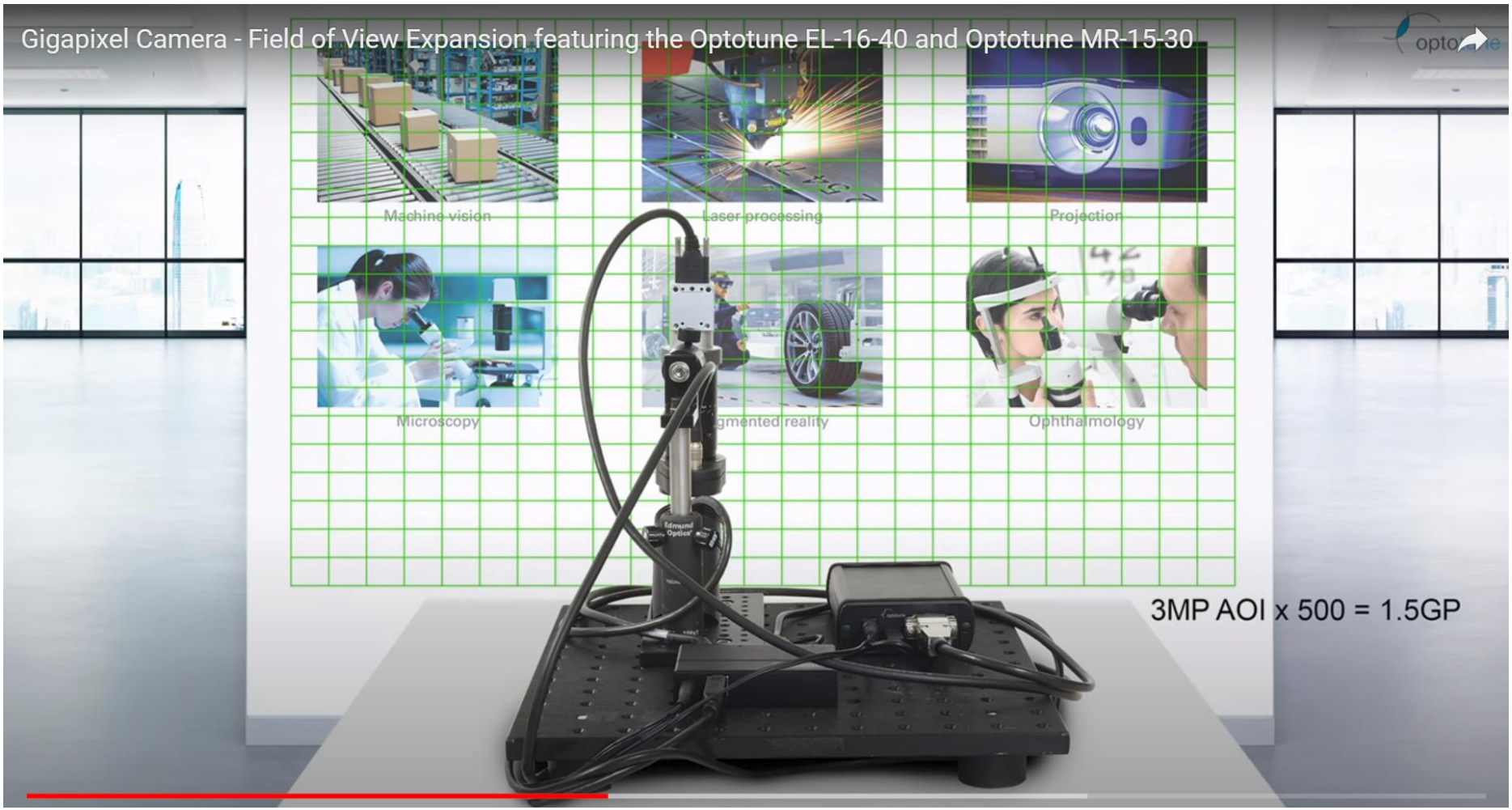
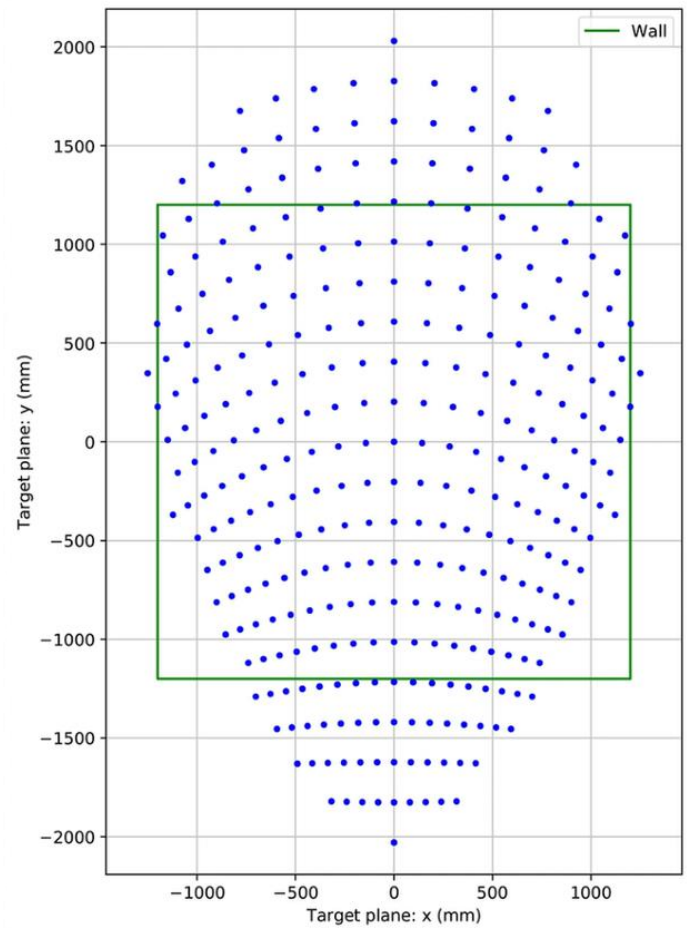
Gigapixel Camera – Field of View Expansion allows to take pictures with 1.5GP resolution

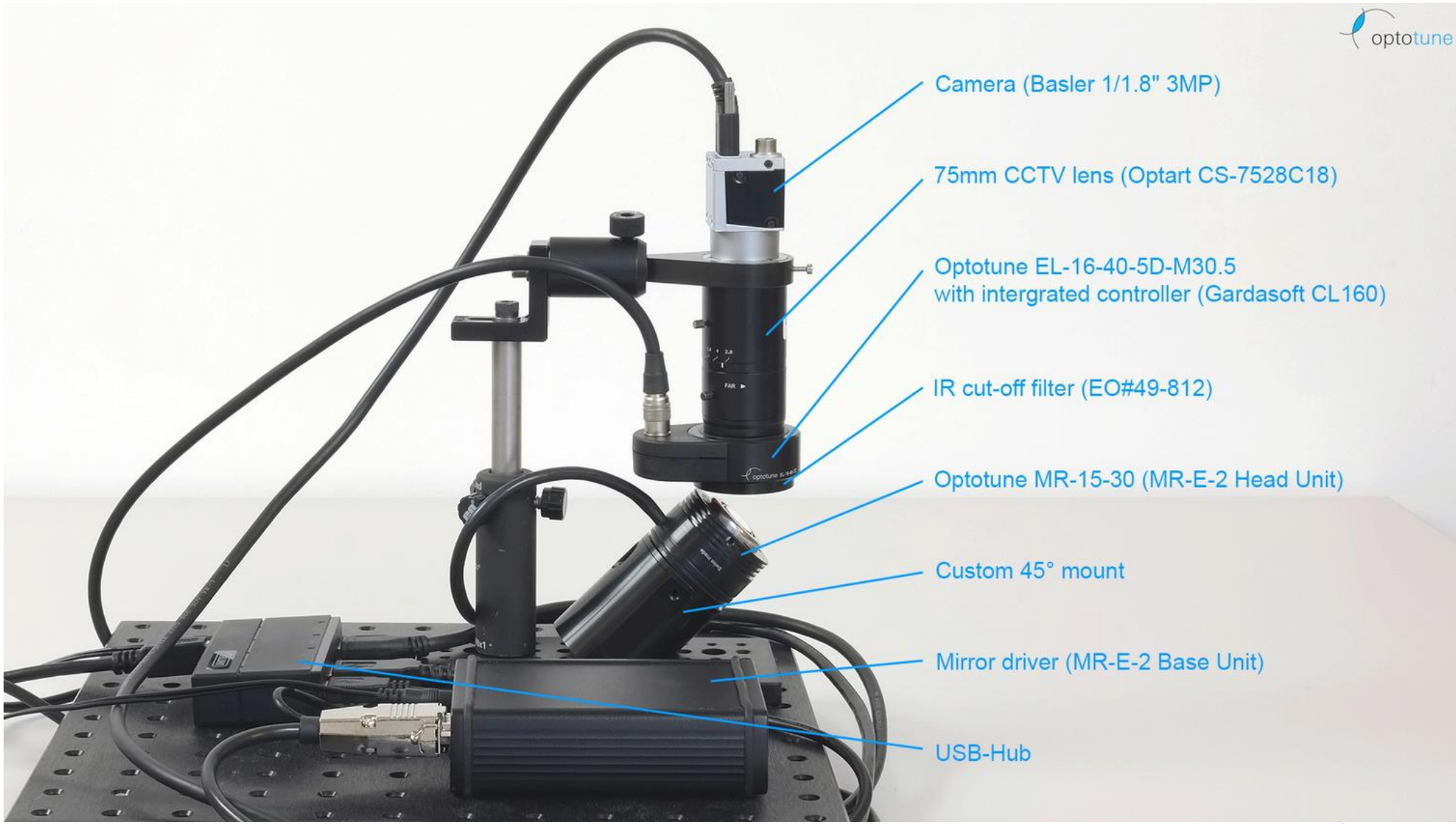


https://www.youtube.com/watch?v=JTKxO5Wb-0I

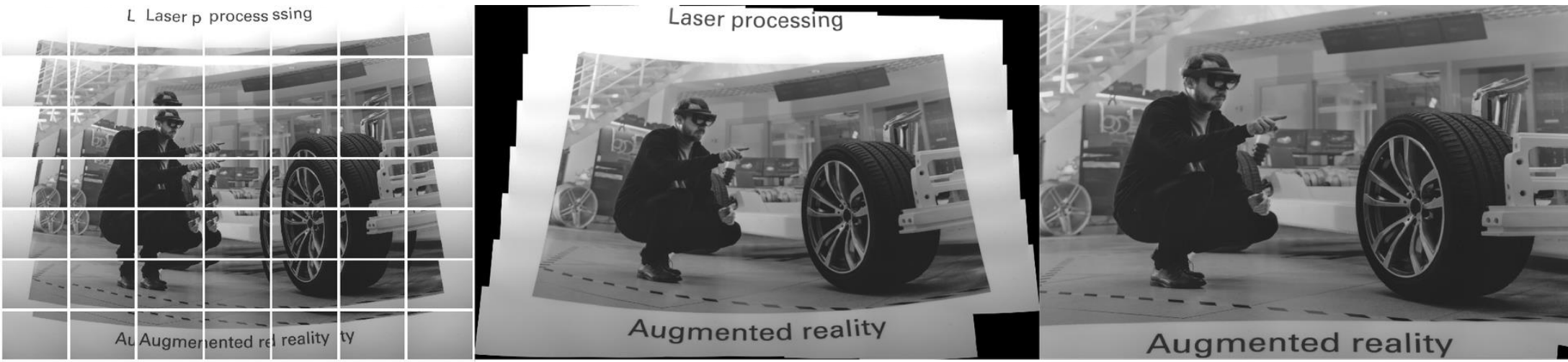
Total FOV provided by the mirror in relation to the wall size



Demo setup for FOV Expansion using Optotune's EL-16-40 and MR-15-30.



Workflow from raw images (A) to stitched (B) and distortion corrected (C) images.



A → Autostitch tool → B → GIMP → C

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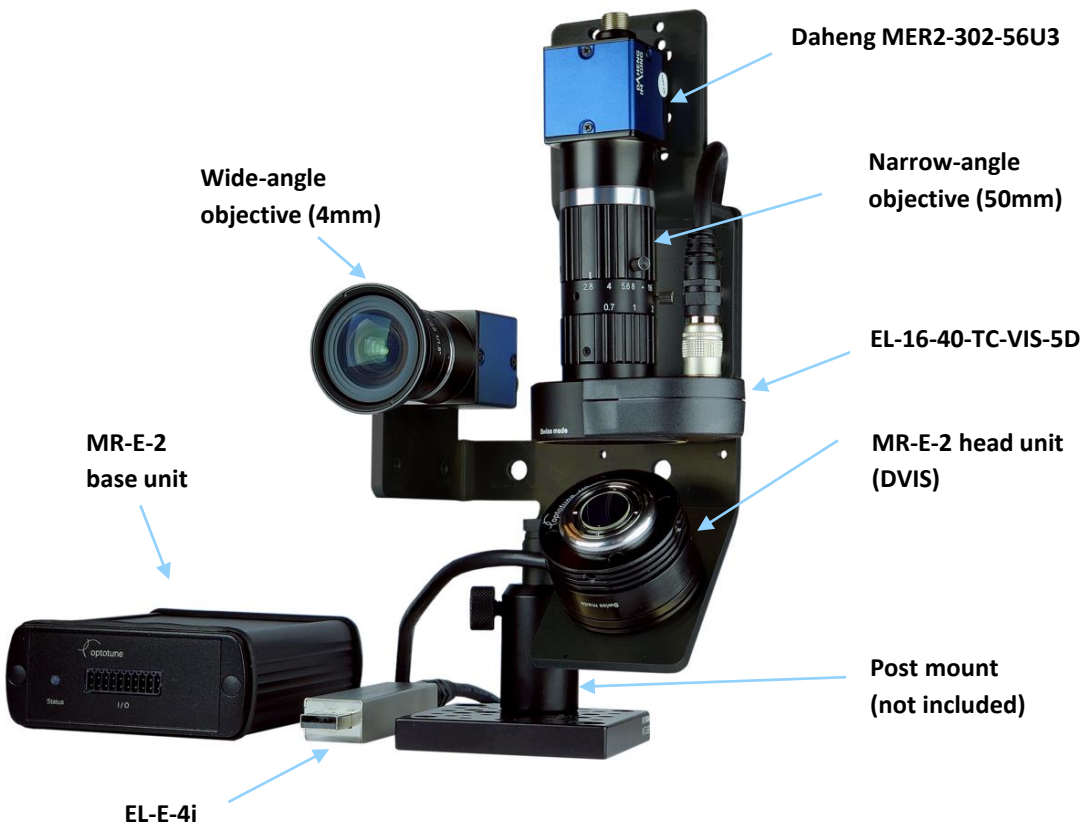
FOV expansion /face recognition devkit



Mechanical specifications

Outer dimensions w/o drivers & cabling (WxDxH)	115 x 84 x 200	mm
Weight		g
Mounting	M4 post / M6 through holes	
Camera cable length	3	m
Lens cable length	1	m
Mirror cable length	1	m

Optical specifications

Resolution	4.5 (50 mm lens) 3.5 (75 mm lens)	mdeg
Focal length of wide-angle lens	4	mm
F# of wide-angle lens	f/2.0	
Wide-angle FOV (H x V)	67 x 84	°
Focal length of narrow-angle lens	50 or 75	mm
F# of narrow-angle lens	f/2.8 (50mm) f/2.8 (75mm)	
Narrow-angle FOV (H x V)	8.2 x 6.1 (50 mm lens) 5.5 x 4.1 (75 mm lens)	°
Focal tuning range	250 – Infinity (50 mm lens)	mm
Camera	Daheng MER2-302-56U3C	
Sensor	Sony IMX265 CMOS 1/1.8"	
Camera resolution	2048 x 1536	pxl
Pixel size	3.45 x 3.45	µm
Sensor size	7.18 x 5.32	mm
Shutter type	global	

Electrical specifications and interfaces

Power consumption (typ.)	10	W
Camera interface	USB 3.0	
Mirror controller (MR-E-2) interface	USB 2.0	
Lens controller (EL-E-4i) interface	USB 2.0	USB extension included

Standard configurations

Configuration	Objective
FOV Expansion Dev Kit (50 mm)	50 mm
FOV Expansion Dev Kit (75 mm)	75 mm

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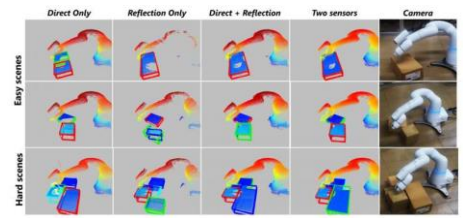
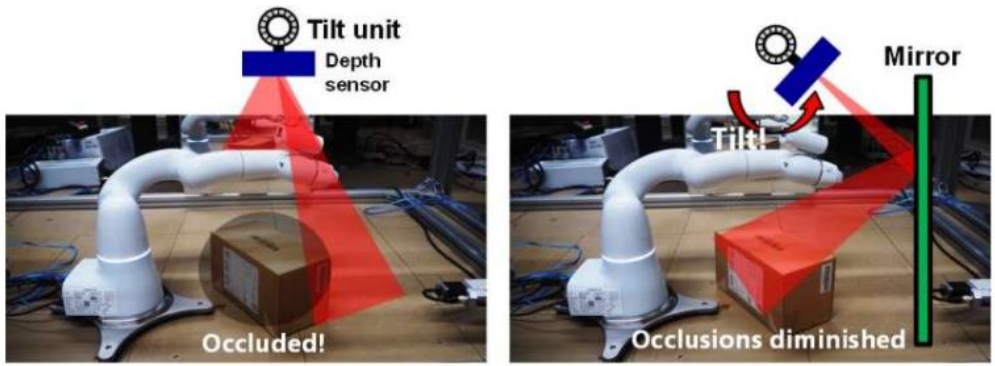
Minimize occlusions in robotic systems



SEPTEMBER 21, 2021 FEATURE

A robot vision system that diminishes occlusions using mirror reflections

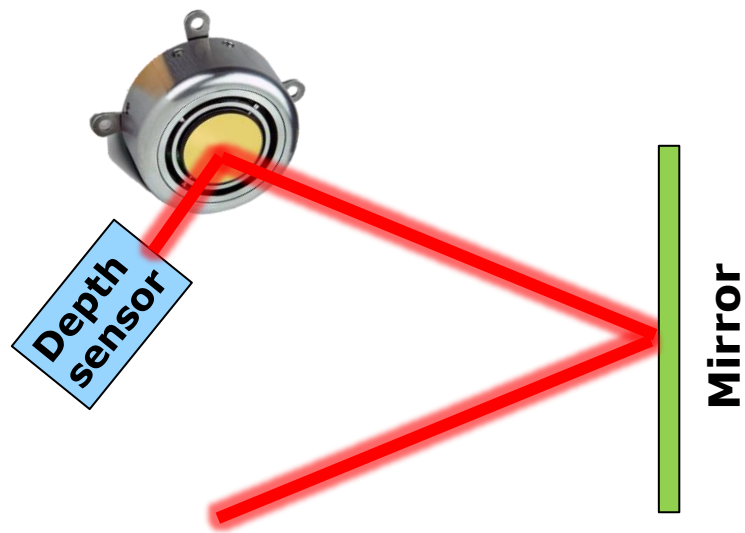
by Ingrid Fadelli , Tech Xplore



The concept of our tilt-based reflection sensing system. Credit: Yoshioka et al.

- Occlusion stands as a large challenge in robot vision
  - Danger of overlooking or even damaging the target
  - Occlusions are even more challenging when multiple robots work under the same environment

- Optotune solution:
  Instead of tilting the sensor use our fast-steering 2D mirror:
- Advantages:
  - Faster dynamic
  - No complex sensor tilt mechanism required



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Automotive applications

Varroc Lighting Systems headlamp with integrated LiDAR using Optotune's MR-15-30

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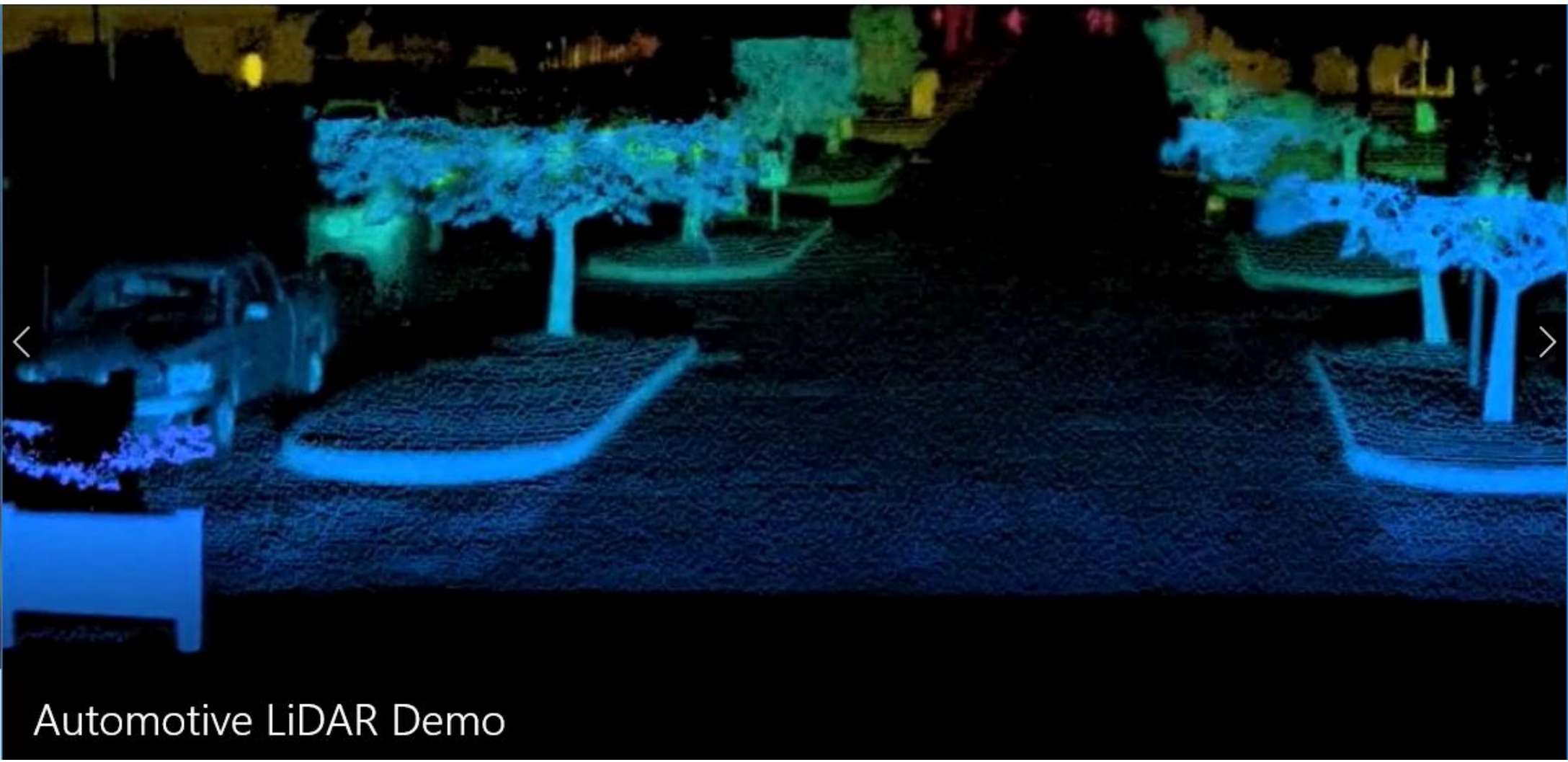
Line scan Lidar demo on car using the MR-15-30 mirror



[Video click here]

MR-15-30 for adaptive headlights

- Compact
- Fast
- Large FOV (100°)
- Robust (>1B cycles)

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Foviated vision system looks far ahead

AOI: 0.3° FOV

It would require a 400MP camera to detect a traffic sign in 100m distance in a 100°x40° FOV without our mirror.

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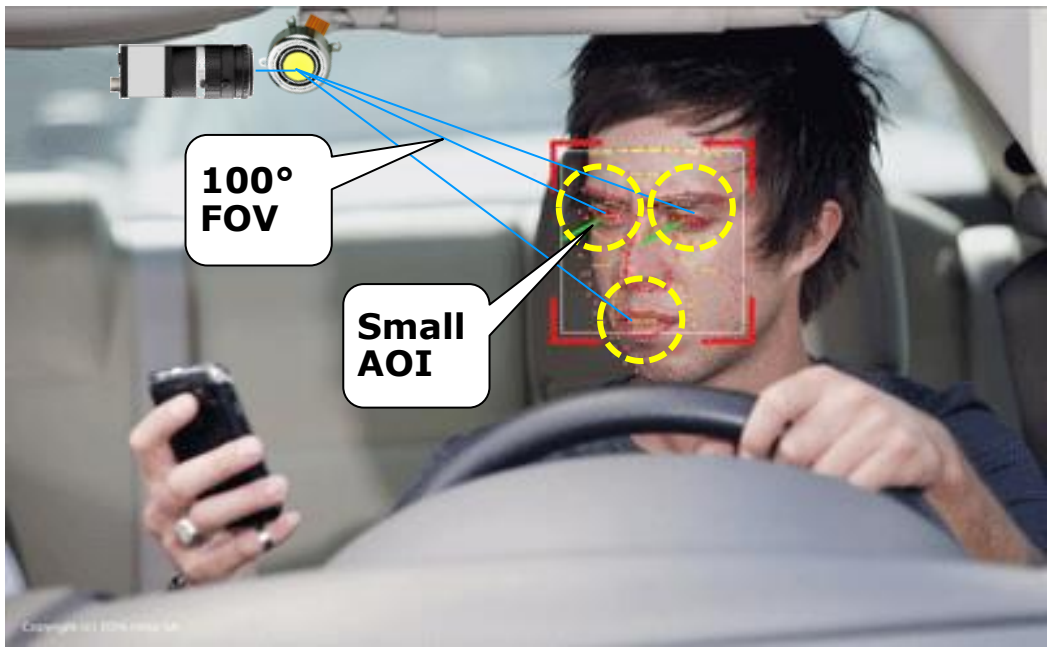
Area of interest (AOI) selection



- Select a small area of interest (AOI) out of a large field-of-view (FOV)

  → High resolution image with a small image sensor
- Scan between multiple AOIs
- Applications:
  - Iris scanning
  - Driver fatigue detection

Free-space communication

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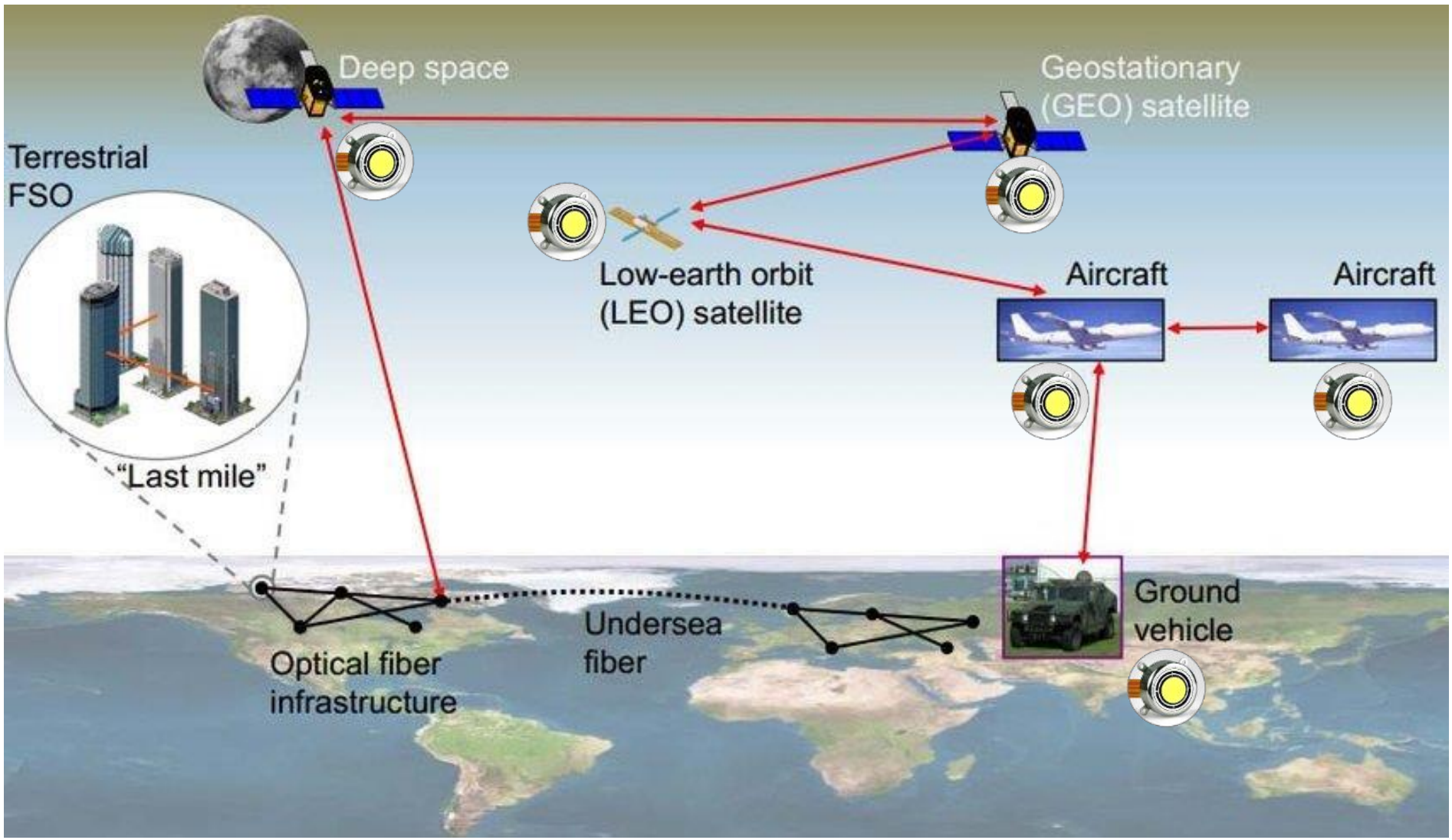
MR-15-30 - coarse and fine-steering unit



Picture courtesy of DARPA

Medical

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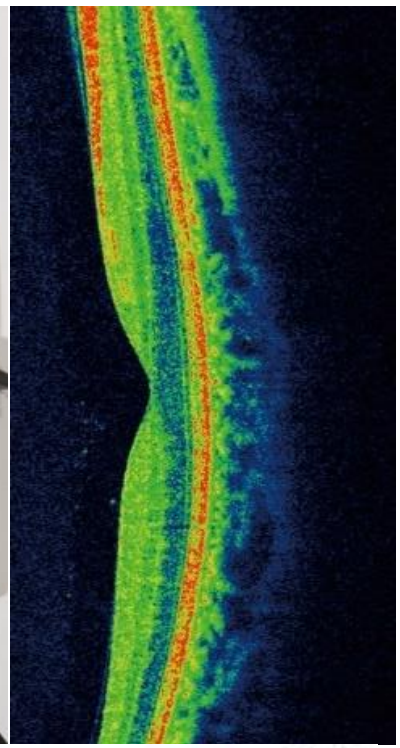
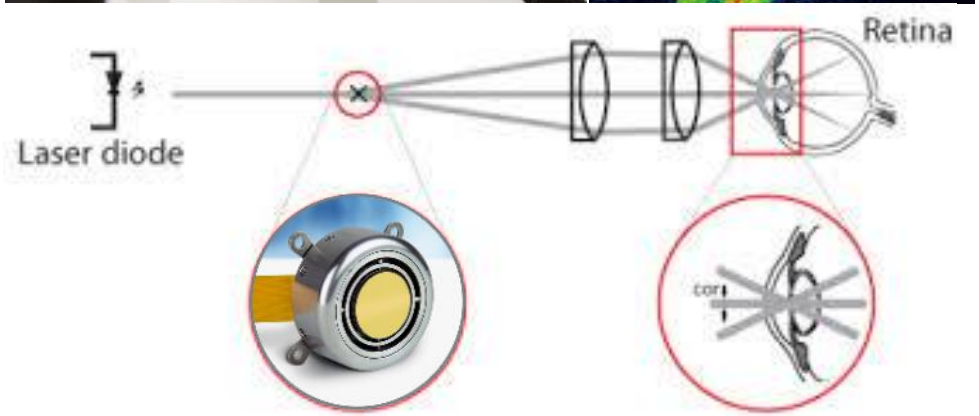
Optical coherence tomography (OCT)





- Compact
- Large FOV
- Almost no lateral beam shift

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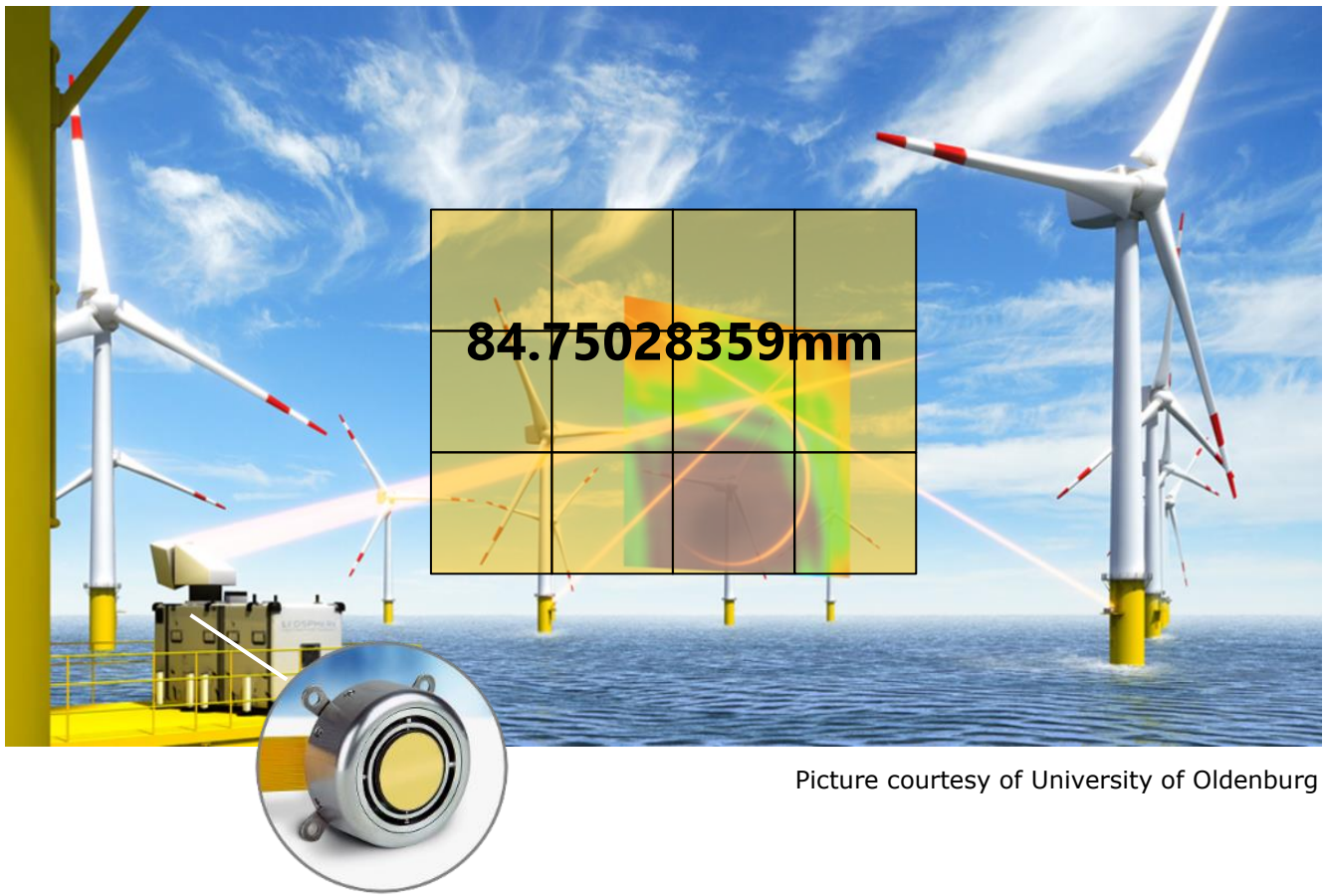
UV disinfection

- The MR-15-30 with a custom mirror coating (e.g. protected Al) would be suitable for UV disinfection

Boeing's self-cleaning lavatory zaps germs with UV light

Metrology

MR-15-30 benefits wind LiDAR systems



Picture courtesy of University of Oldenburg

- ‘Tiled’ LiDAR image
- Larger FOV
- Higher resolution

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shaping the future of optics