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Optotune

Enabling optical innovations

November 2023

Optotune Switzerland AG | Bernstrasse 388 | CH-8953 Dietikon | Switzerland
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Agenda

- Introduction
- Liquid Lenses
  - Solutions for fast focusing
  - Optics configuration tools
  - Applications
- Fast Steering Devices
  - Applications
- Beam Shifting Devices
  - Applications

Optotune on a page

optotune
shaping the future of optics

Purpose: Make optical innovation happen

Established in 2008

Leader in light controlling components

212 employees
- 105 in Switzerland
- 95 in Slovakia
- 12 in sales offices

Highly innovative
- 48% of staff with Master, 20% with PhD degree
- 28% of revenue spent on R&D
- >200 patents filed, >60 granted

Key markets
- Medical
- Industrial
- Consumer
- Automotive

Privately owned

SIQT Innovations Award 2020 >
InVision Top Innovations 2017 >
Vision Systems Innovator Award 2016 >
Swiss Economic Award 2014 >
No. 1 Startup in Switzerland 2011 >
Prism Award 2011 >
Swiss Technology Award 2010 >
Winner of Venture 2008 >
ETH Spin-off 2008 >

swiss safety center ISO 9001 certified system

Optotune’s global presence

Dietikon, Switzerland

- HQ
- R&D hub
- Manufacturing

Boston, USA

- North American sales office

Taipei, Taiwan

- Asian sales office

Trnava, Slovakia

- Manufacturing
- Software development

Optotune has built up a network of 28 sales partners in over 30 countries.

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Contract manufacturers we supply to

EXCELITAS TECHNOLOGIES®

pci

JABIL

flex®

NOVEL® OPTICS

DAIWON

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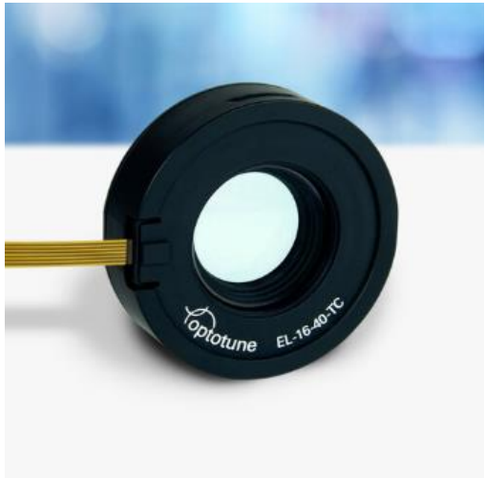
Product Portfolio

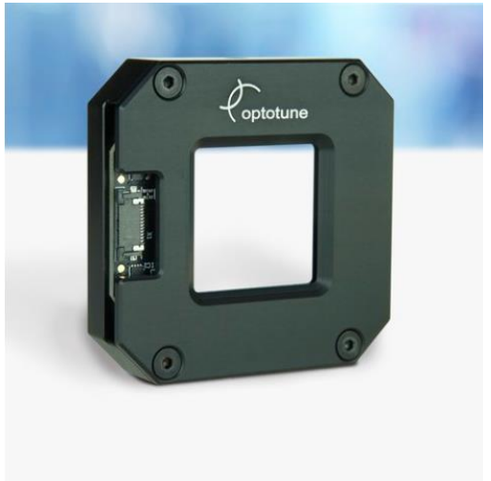
Our solutions for Machine Vision

Focus tunable lenses



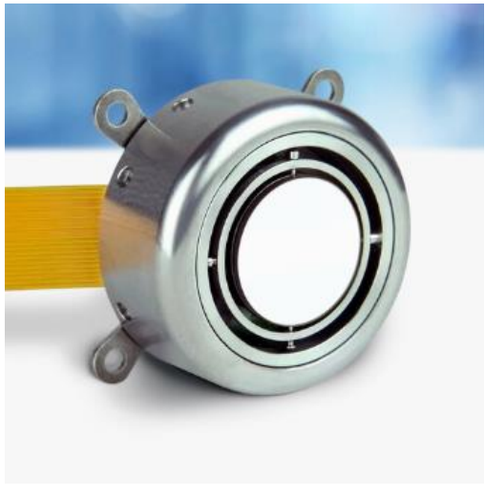
- Fast autofocus
- Fast detection
- Image stacking

Beam shifting devices

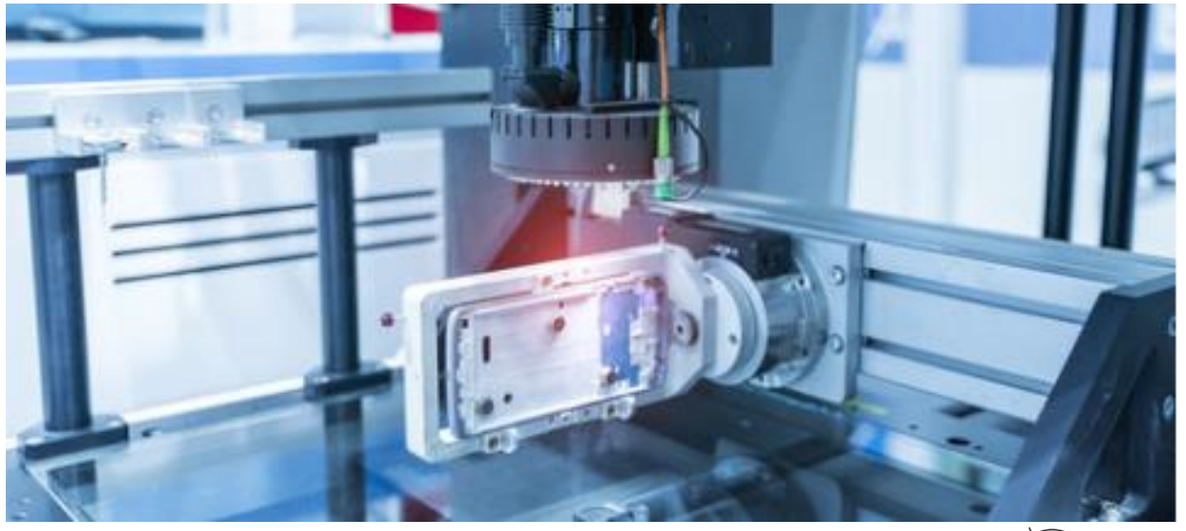


- Fast transition time
- Reliable over time
- Beam shifts up to 4.8um

Beam steering devices



- Sole reflection
- Wide angular range
- Compact



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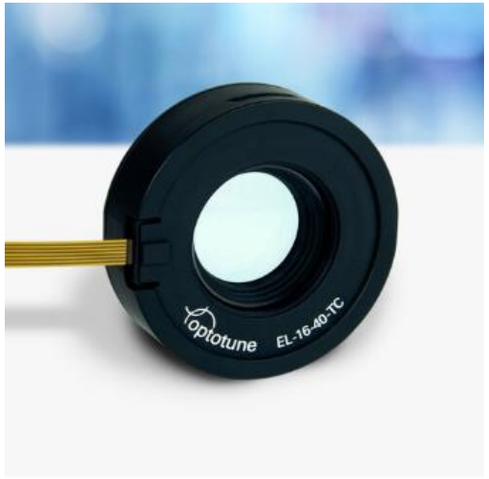
Product Portfolio

Our solutions for Machine Vision

Focus tunable lenses



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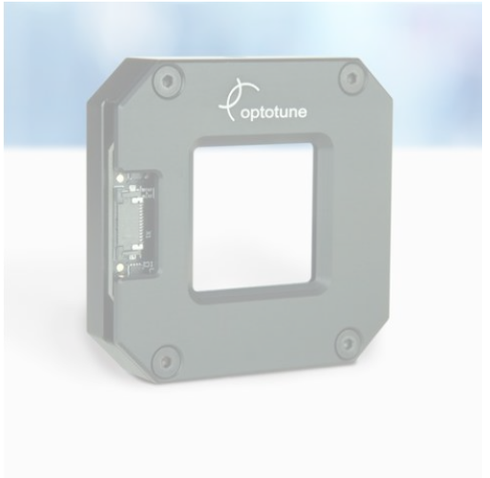
Beam shifting devices



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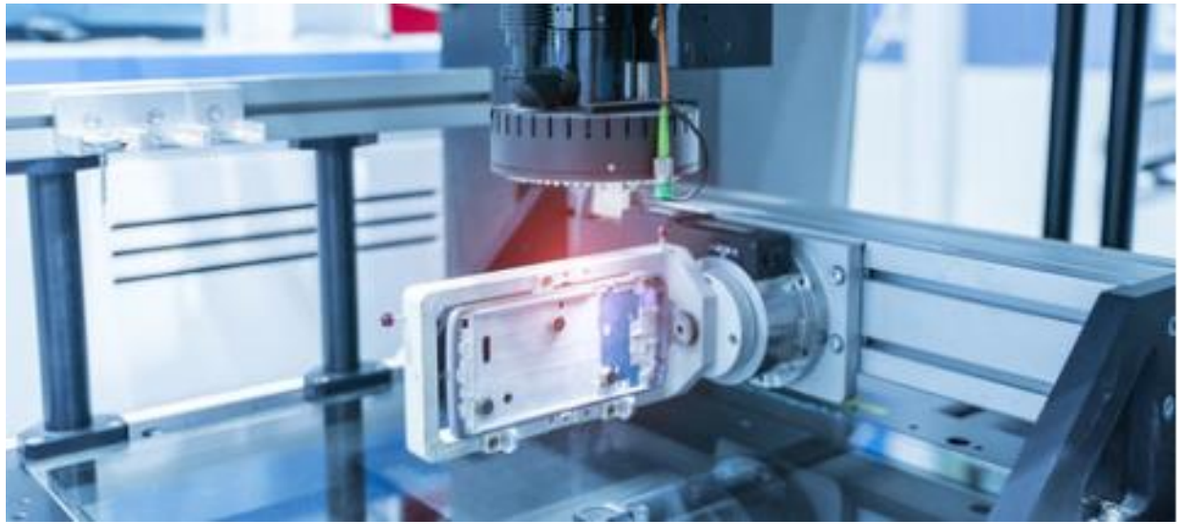
Beam steering devices

- Sole reflection
- Wide angular range
- Compact



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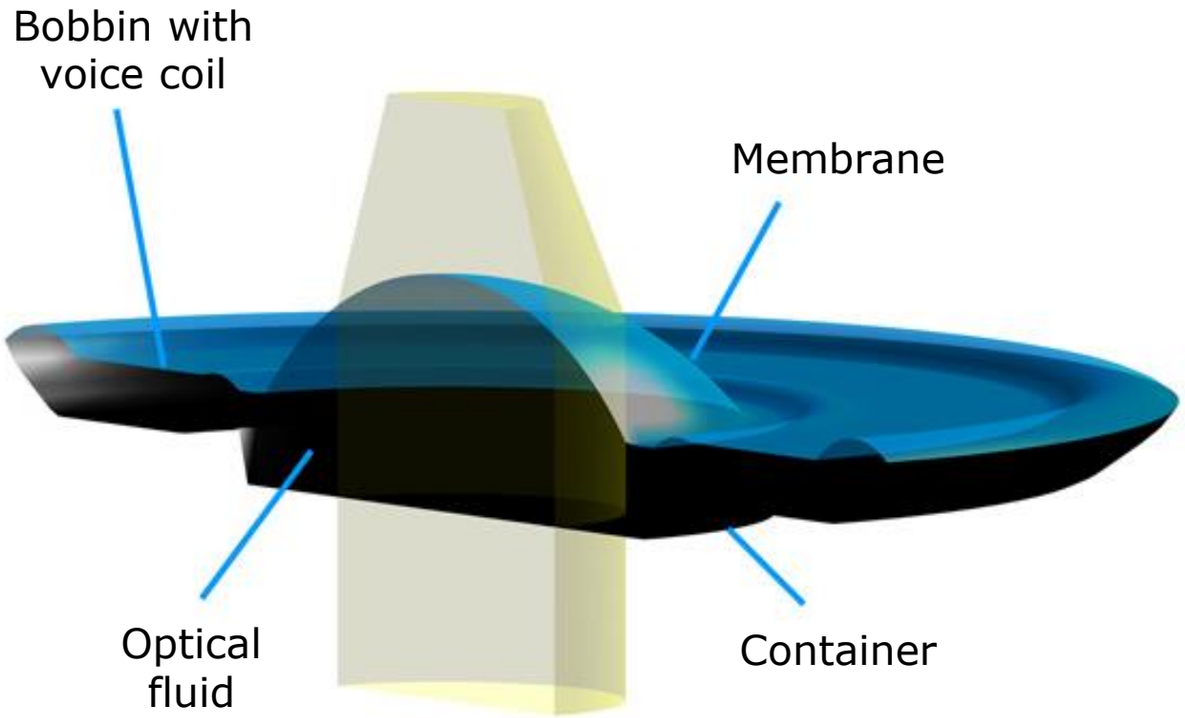
Working Principle

Membrane with fluid and actuator

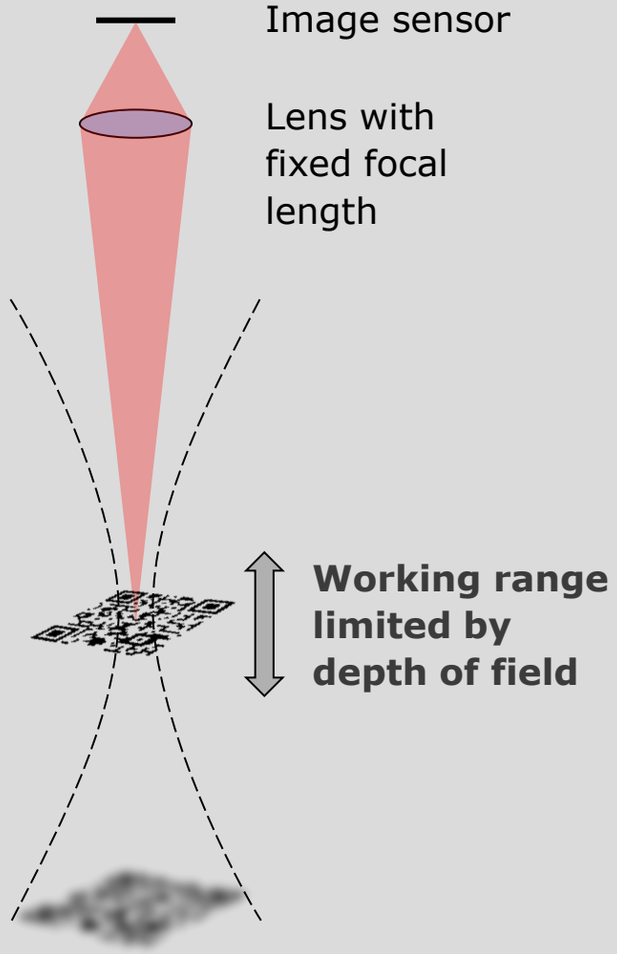


In action:
How current influences the membrane shape

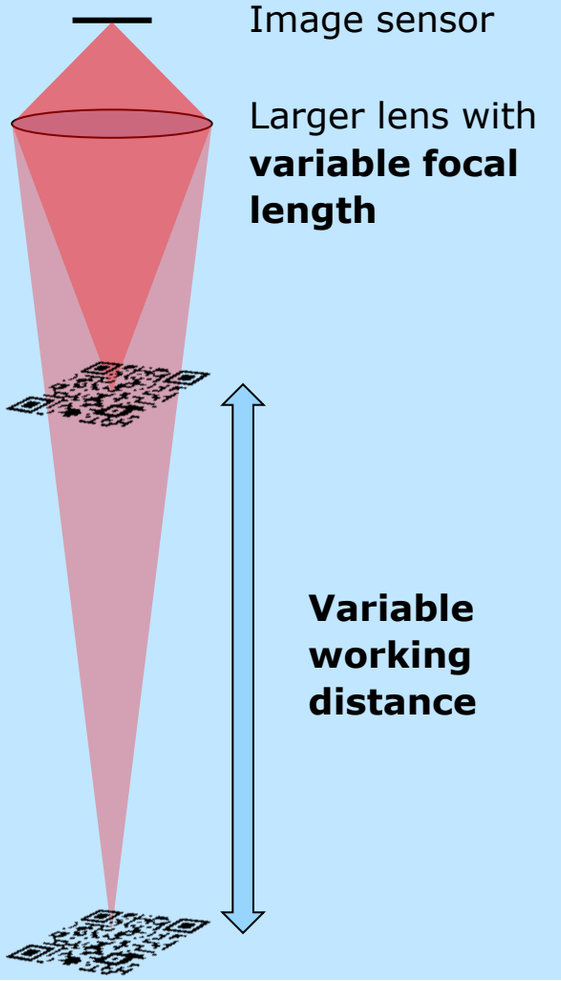
See also: https://www.optotune.com/tunable-lenses

The ideal focusing solution for machine vision

Fixed focus optics



Liquid lens approach



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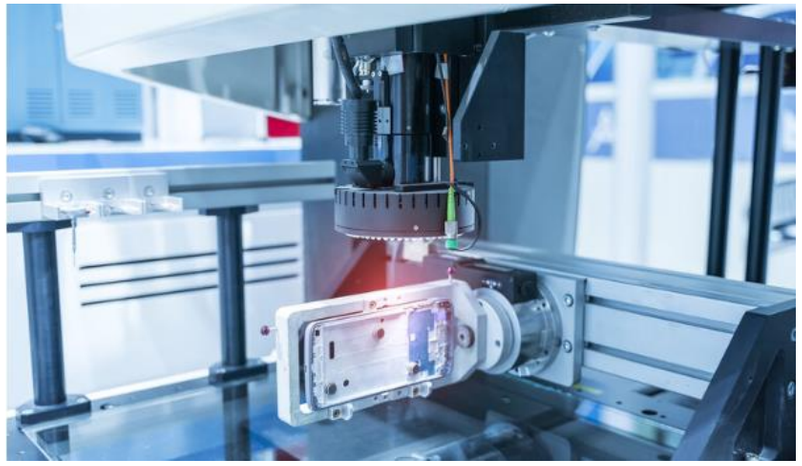
The natural way to focus: Like your eyes but faster!

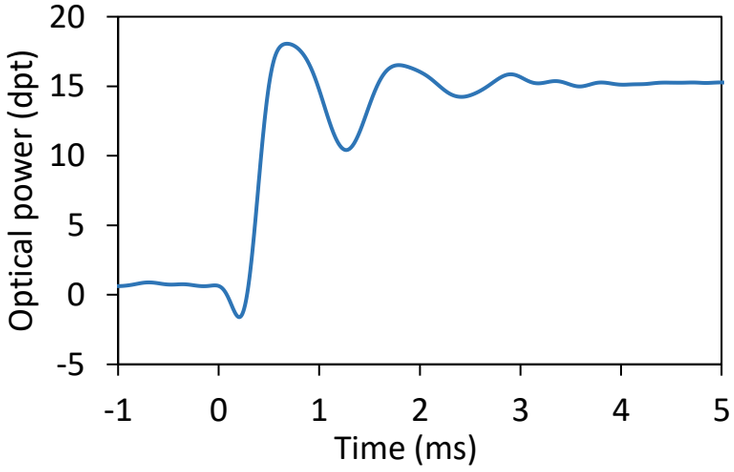
Specifications

- Apertures from 3 to 30mm
- Large working distance range
- Low dispersion (Abbe# V>100)
- >10^9 cycles
- High repeatability <0.1 dpt
- Response time of few milliseconds

Benefits

- Sensor sizes 1/3” to 40mm supported
- Maximum flexibility with low f-numbers
- No color aberrations
- Long Lifetime
- One-time calibration
- Higher throughput





EL-3-10
Step response

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Both off-the-shelf lens combinations and integrated, optimized designs are available

Off-the-shelf lenses

+

S-mount

C-mount

M42-mount

Telecentric

Objectives

Optimized designs

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Our Lens Partners

EVETAR®

Edmund optics | worldwide

Kowa

LINKHOU灵猴

OPT® Machine Vision

SILL OPTICS

NAVITAR

OPTO ENGINEERING

QIOPTIQ
Photonics for Innovation
An Excelitas Technologies Company

VS TECHNOLOGY
MACHINE VISION OPTICS

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Electrical lens modules (ELMs) achieve optimized performance thanks to integration of the EL

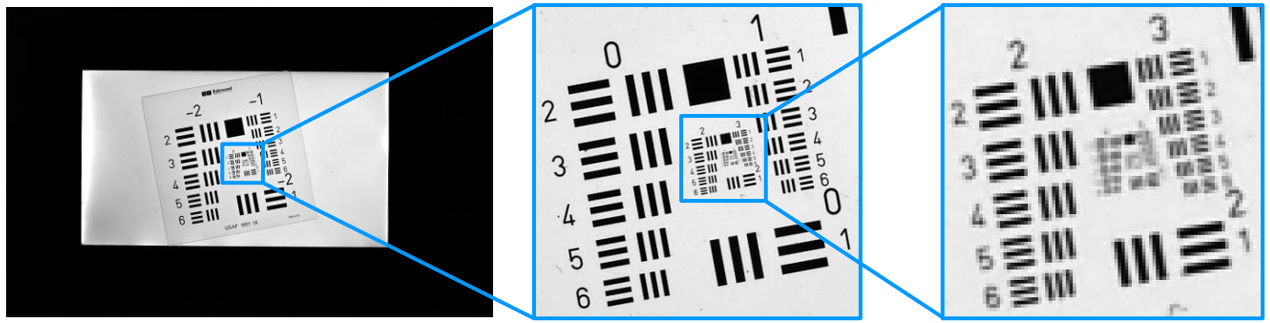
Advantages

- Most compact solutions
- Low f-numbers without vignetting
- Modules are fully tested
- Sensor sizes up to 1.1”
- Focal lengths from 5 to 300mm

Limitations

- Not all focal length / sensor combinations available yet

Example: ELM-25-2.8-18-C achieves **150-180 lp/mm** on whole 1.1” over 250-∞ WD range!



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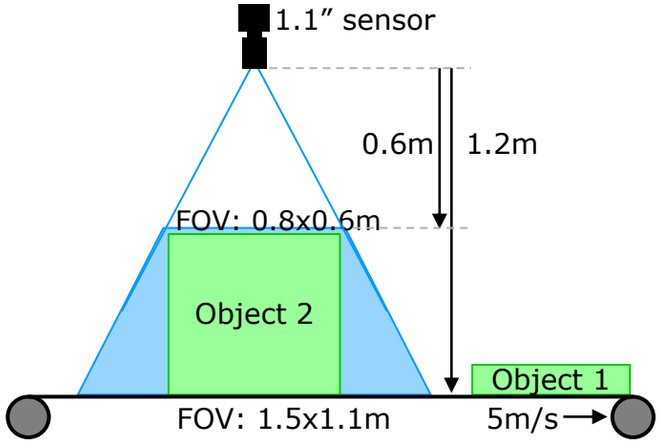
Currently 17 ELMs available from 5 to 300mm focal length

Product	Focal length (mm)	F #	Pixel size (recommended)	Sensor format	Mount
ELM-5-5.0-7-S	5 mm	F/5.0	2.2 um	1/2.5"	S
ELM-16-5.4-8-S	16 mm	F/5.4	1.8 um	1/2.3"	S
ELM-12-5.6-9-S	12 mm	F/5.6	2.4 um	1/1.7"	S
ELM-16-5.6-9-S	16 mm	F/5.6	2.4 um	1/1.7"	S
ELM-25-5.6-9-S	25 mm	F/5.6	2.4 um	1/1.7"	S
ELM-12-2.8-18-C	12 mm	F/2.8	2.4 um	1.1"	C
ELM-25-2.8-18-C	25 mm	F/2.8	2.4 um	1.1"	C
ELM-35-5.6-14-C	35 mm	F/5.6	3.0 um	2/3"	C
ELM-35-5.6-16-C	35 mm	F/5.6	3.0 um	1"	C
ELM-35-3.5-16-C-NIR	35 mm	F/5.6	3.0 um	1"	C
ELM-50-2.8-18-C	50 mm	F/2.8	3.0 um	1.1"	C
ELM-60-4.0-24-C	60 mm	F/4	5 um	4/3”	C, M42
ELM-75-4.0-8-C-NIR	75 mm	F/4	3.45 um	1/2”	C
ELM-75-3.9-16-C	75 mm	F/3.9	2.4 um	1”	C
ELM-80-4.0-24-C	80 mm	F/4	5 um	4/3”	C, M42
ELM-150-7.5-11-C	150 mm	F/7.5	5 um	2/3”	C
ELM-300-10.0-11-C	300 mm	F/10	8 um	2/3”	C

Lens module example:
12 mm lens with integrated EL-16-40 by VST

ELM-12-2.8-18-C



High resolution and large field of view

- Ideal for code reading and OCR applications e.g. in logistics

Working distance range from 250mm to infinity

- Best MTFs between 500 to 1000mm
- High optical leverage (1.13m/dpt)

Resolution (for 2.4um pixels)

- Image center at Nyquist limit (up to 208 lp/mm)
- Image corners between 90-168 lp/mm
- Best resolution at F/5.6

Image quality

- No vignetting up to 1.1” format at F/2.8
- Barrel distortion, which can be corrected digitally

Resources

Test report

Lens module example:
25 mm lens with integrated EL-16-40 by Evetar

ELM-25-2.8-18-C

High resolution and medium field of view

- Ideal for code reading and iris recognition

Working distance range from 250mm to infinity

- Best MTFs between 500 to 1000mm
- High optical leverage (0.61m/dpt)

Resolution (for 2.4um pixels)

- Image center at Nyquist limit (169-180 lp/mm)
- Image corners between 157-174 lp/mm

Image quality

- No vignetting up to 1.1” format
- Very low distortion
- Great polychromatic light performance
- Best contrast with monochromatic light (red)

Resources

Test report

Lens module example:
300 mm lens with integrated EL-16-40 by Sill Optics

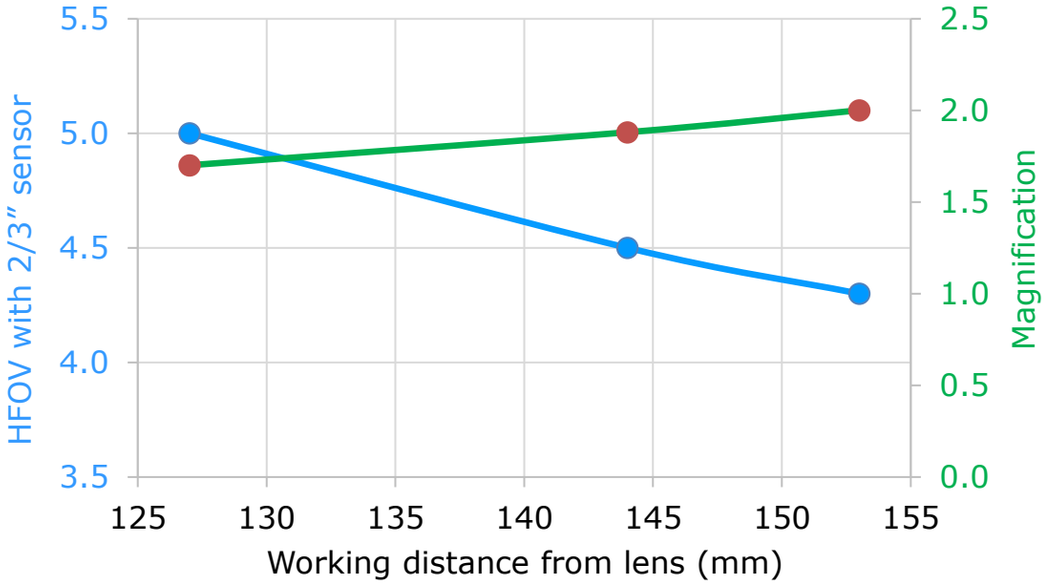
ELM-300-10.0-11-C

High resolution and small field of view

- Ideal for imaging via galvo mirrors

Z range

- 26mm using 160mm f-theta lens



Resources

Test report

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Front-lens configuration with C-mount lenses

Fixed focal length lens

EL-16-40-TC-VIS-5D-M25.5
-M27
-M30.5

Advantages

- Simple mounting on filter thread
- Many off-the-shelf lenses available
- Large working distance ranges

Limitations

- 16mm clear aperture liquid lens limits field of view to 30° horizontal

Working distance ranges from infinity to about 100mm

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Back-lens configuration with C-mount lenses for macro imaging

C-mount camera

Optotune lens
EL-10-30-Ci-VIS-LD-MV
or
EL-16-40-TC-VIS-5D-C

50mm lens
e.g. Tamron 23FM50SP
focused at ∞

Advantages

- Simple mounting with C-mount threads
- Sensor sizes up to 1.1”
- Good results also with smaller EL-10-30

Limitations

- Working distance typically 160mm or less
- Z-range up to 43mm

Specs	EL-10-30	EL-16-40	
Magnification	0.37x	0.35x	
WD @0dpt	140	150*	mm
Z range (7dpt)	24	43	mm
HFOV @0dpt on 2/3” sensor	24	26	mm

*280-420mm WD possible with Schneider Kreuznach Topaz 50mm & custom adapter

Only works well for lenses with focal length >= 50mm

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Back-lens configuration with M42-mount lenses allows for 30mm image circle

Enough spacers to match flange to sensor distance

EL-16-40-TC-VIS-M42

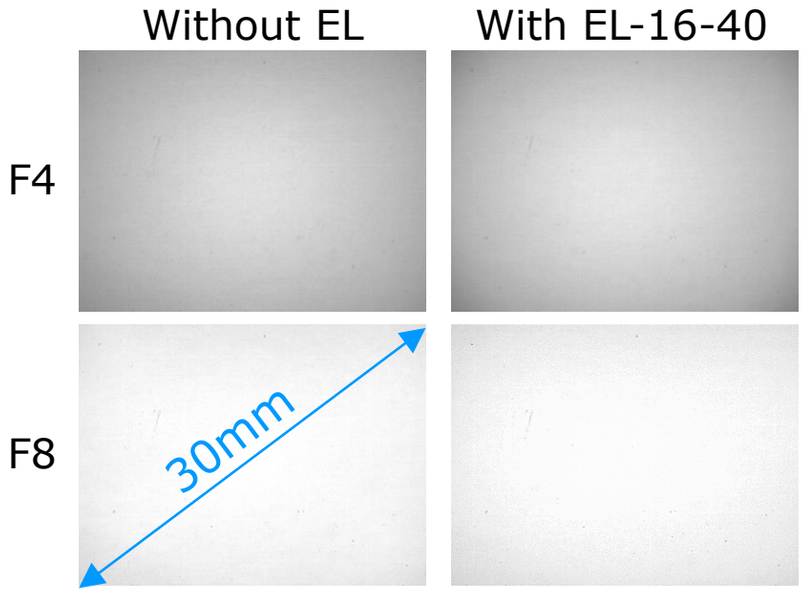
M42-mount lens e.g. Apo-Componon 60mm or Zeiss Interlock 35mm

Advantages

- Sensor sizes up to 30mm
- High resolution & light sensitivity
- Working distances from 250mm to infinity

Limitations

- M42 mount camera and optics can be costly



Test report: https://www.optotune.com/s/Optotune-EL-16-40-TC-VIS-5D-M42-SK-Apo-Componon-60F4.pdf

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Combining an EL with off-the-shelf telecentric lenses is possible, but not ideal

Front-lens configuration

Advantages

- Large WD range

Limitations

- No object side telecentricity
- Largest object size << 16mm
- Might be difficult to mount

Back-lens configuration

Optical leverage:

$0.5[mm/dpt]\ /\ PMAG^2$

Advantages

- Simple mounting with C-mount threads
- Maintains object side telecentricity

Limitations

- Small WD range & large mag change
- Only works well for 0.3 to 0.8X

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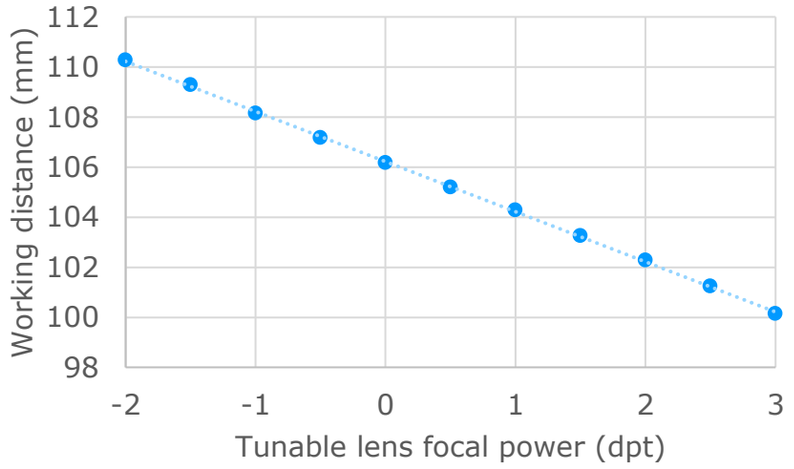
Optimized telecentric lenses include EL close to aperture stop

Advantages

- Large z-range, about 100x the usual DOF
- WD changes linearly with optical power
- Magnification change is linear and low, 0.1-0.8% per mm
- No vignetting, distortion or loss of resolution due to EL
- 80 models available off-the-shelf from 0.13x to 6x

Limitations

- Non-standard magnifications require custom design



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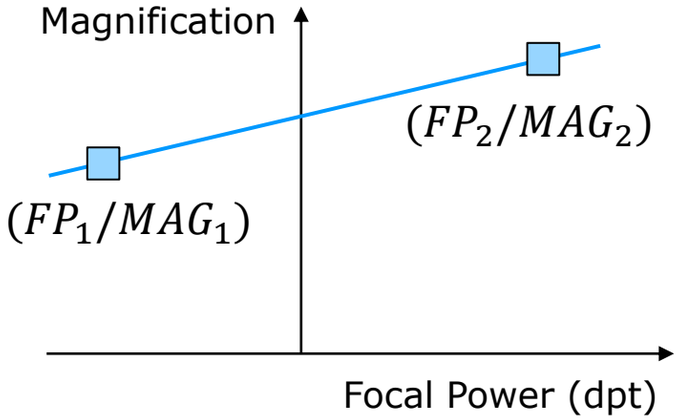
How to measure reliably when magnification changes

- When adjusting the working distance with a telecentric liquid lens the magnification changes slightly
- The change is usually linear and can easily be calculated as follows:

- Whereas a & b can be derived from the datasheet or from two calibration points as follows:

$$MAG = a \cdot FP + b$$

$$a = \frac{MAG_2 - MAG_1}{FP_2 - FP_1} \quad b = MAG_1 - a \cdot FP_1$$



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Optimized telecentric lenses from Sill Optics from with mags from 0.13X to 3.0X

part number	magnification	working distance [mm]	clear aperture [mm]	max. sensor size [mm]	wave-length [nm]	NA	max. distortion [%]	length [mm]	mount
S5VPJ1860 **	0.133	79.7 – 434.1	153	16.0 (1")	450 - 680	0.01	0.35	587.0	C-mount
S5VPJ5060 **	0.192	215.3 – 366.6	83	11.0 (2/3")	450 - 680	0.01	0.7	357.6	C-mount
S5VPJ1565	0.193	193.6 – 338.7	123	16.0 (1")	450 - 680	0.01	0.5	396.3	C-mount
S5VPJ6060 *	0.289	137.4 – 205.8	86	16.0 (1")	450 - 680	0.02	0.5	283.4	C-mount
S5VPJ1260	0.311	155.1 – 211.2	62	16.0 (1")	450 - 680	0.02	0.45	241.2	C-mount
S5VPJ3060 **	0.343	133.1 – 184.4	58	8.9 (1/1.8")	450 - 680	0.02	0.4	224.9	C-mount
S5VPJ2660 **	0.374	133.4 – 172.8	48	11.0 (2/3")	450 - 680	0.02	0.65	203.5	C-mount
S5VPJ2060 **	0.499	102.8 – 125.5	29	8.0 (1/2")	450 - 680	0.02	0.3	162.7	C-mount
S5VPJ2898 *	0.578	81.8 – 98.2	60	16.0 (1")	450 - 680	0.03	0.5	161.7	C-mount
S5VPJ1560 **	0.659	79.2 – 91.6	28	8.0 (1/2")	450 - 680	0.03	0.36	133.9	C-mount
S5VPJ0625 **	1.000	179.1 – 196.5	29	16.0 (1")	450 - 680	0.03	0.8	142.5	C-mount
S5VPJ0627 **	1.500	152.4 – 172.3	29	21.4 (1.25")	450 - 680	0.04	0.45	179.2	C-mount
S5VPJ0422 **	2.000	100.5 – 109.8	26	32.0	450 - 680	0.04	0.6	133.4	M42x1
S5VPJ0422/216	2.000	100.5 – 109.8	26	16.0 (1")	450 - 680	0.04	0.6	156.0	C-mount
S5VPJ0426 **	2.500	94.8 – 104.6	26	35.0	450 - 680	0.05	0.4	160.2	M42x1
S5VPJ0420 **	3.000	91.2 – 101.2	26	35.0	450 - 680	0.06	0.2	186.1	M42x1

* Lenses also support coaxial illumination

** Lenses available upon request

Test report: https://www.optotune.com/s/Optotune-EL-16-40-TC-with-Sill-Correctal-T_20-telecentric-lens.pdf

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Optimized telecentric lenses from Opto Engineering and Edmund Optics

PMAG	Model	Camera Sensor Format	F#	Working Distance (mm)
0.243x	TCEL23036 (a)	2/3"	F/8	73.3 - 122.8
0.50x	TCEL050	2/3"	F/12	112.2 - 146.0
0.67x	TCEL066	2/3"	F/12	112.3 - 146.0
0.75x	TCEL075	2/3"	F/12	112.5 - 146.0
1.00x	TCEL100	2/3"	F/12	107.0 - 124.0
1.50x	TCEL150 (b)	2/3"	F/16	117.9 - 142.1
2.50x	TCEL250 (b)	2/3"	F/20	117.8 - 142.2
3.50x	TCEL350 (b)	2/3"	F/24	117.8 - 142.2
0.15x	EO 36-188	1/2"	f/10	169 – 265
0.24x	EO 36-189	1/1.8"	f/10	91 – 173
0.37x	EO 36-190	1/1.8"	f/10	84 – 101
0.75x	EO 36-192	2/3"	f/10	85 – 99

Test report on TCEL050: https://www.optotune.com/s/Test-report-TCEL050-Opto-Engineering-Optotune.pdf
EO link: https://www.edmundoptics.com/imaging-lenses/telecentric-lenses/mercurytl-liquid-lens-telecentric-lenses/ & https://youtu.be/36qwzmfCriM

Optimized telecentric lenses from VS Technology

PMAG	Model	Camera Sensor Format	F#	Resolution on object (um)*	Working Distance (mm)
1x	VS-THV1-110/S-LQL1	1”	F/10	5.5	106.1 – 120.2
2x	VS-THV2-110/S-LQL1	1”	F/9.6		105.4 – 115.6
2x	VS-TCH2-65-LQL1	2/3”	F/13.5		63.5 – 66.1
4x	VS-TCH4-65-LQL1	2/3”	F/17.5		64.7 – 65.3

Optimized telecentric lenses from Linkhou

PMAG	Model	Camera Sensor Format	F#	Resolution on object (um)*	Working Distance (mm)
0.16x	TS1-0166-258-EL	1"	F/6.8		218 – 293
0.26x	TS43F-0267-208-EL	4/3"	F/7.5		195 – 220
0.28x	TS12-028-115-EL	1/2"	F/4.5		106 – 130
0.35x	TS-0346-138-EL	1"	F/6.5		130 – 150
0.36x	TS23-036-115-EL	2/3”	F/4.5	8.7	100 – 130
0.50x	TS1-05-110-EL	1"	F/7.2		106 – 122
0.56x	TS43-056-200-EL	4/3"	F/8.5		199 – 213
0.6x	TS23-06-115-EL	2/3”	F/4.5	6.9	105 – 125
0.6x	TS11-06-160-EL	1.1"	F/8		156 – 176
0.638x	TS1-0638-70-EL	1"	F/8.6		61 – 70
0.8x	TS1-08-110-EL	1"	F/7.5		104 – 118
1.0x	TST23-1.0-110-EL	2/3”	f/10	5.9	106 – 116
2.0x	TS23-2.0-110-EL	2/3”	f/16	5.0	108 – 112
3.0x	TS1-3.0-110-EL	1"	F/19.6		103 – 118
4.0x	TS1-4.0-110-EL	1”	F/19.6		105 – 118
6.0x	TS1-6.0-110-EL	1"	F/37.7		105 - 116
6.0x	TS28.6mm-6.0-65-EL	1.76”	F/30.2		64 – 70

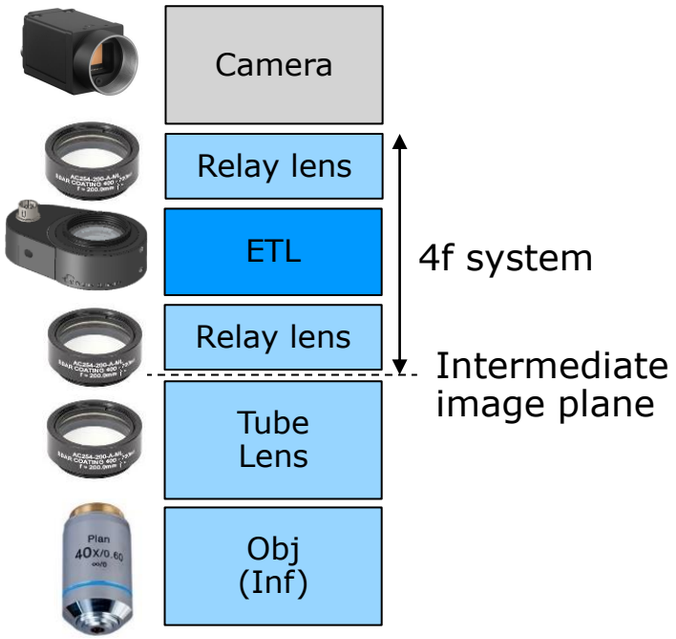
* Resolution is measured using red light with USAF target at a contrast of about 30%

Linkhou link: http://www.linkhou.com/public/portfolio_item/27898/

Integration of liquid lenses in microscopes

Non-telecentric

Telecentric



	Z-range with 5D lens	Mag change*
10x	2560 µm (20D: 10240µm)	7.5%
20x	640 µm (20D:2560 µm)	12.2%
40x	160 µm (20D:640 µm)	23.7%

	Z-range with 5D lens	Mag change
10x	1000 µm	0%
20x	250 µm	0%
40x	60 µm	0%

* Magnification changes are linear, it is possible to compensate via software

Off-the-shelf microscope system for 10-100X

High magnification

- Ideal for EC inspections and bio samples

Z-range

- From 2.8mm with 10x
- To 0.020mm with 100x

Tube lens

- 1x, 0.8x, 0.6x

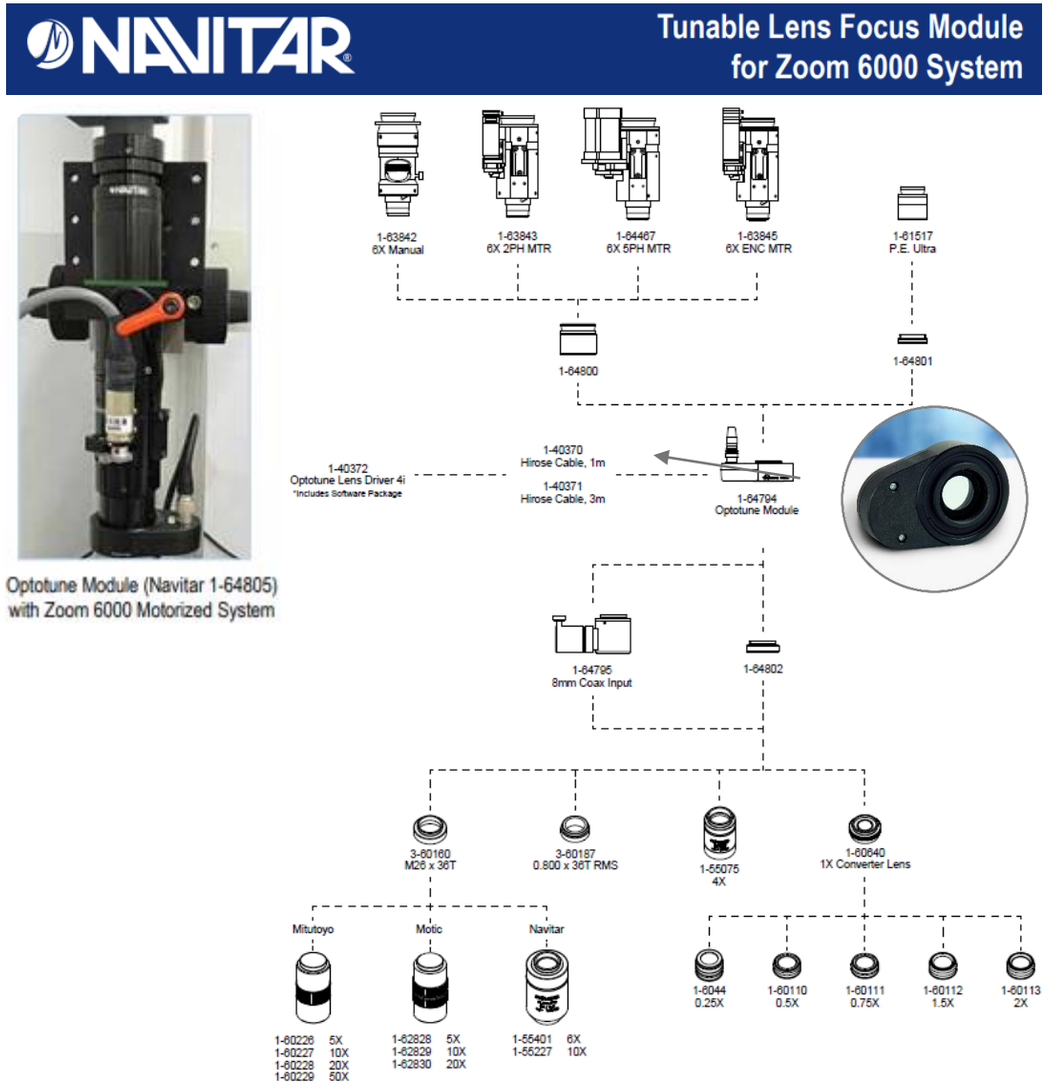
Sensor size

- Up to 1.1” format

Objective	10x	20x	40x	100x
Tuning Range (mm)	2.80	0.51	0.13	0.020
FOV 1/2.3” (mm)	0.62 x 0.46	0.31 x 0.24	0.16 x 0.12	0.062 x 0.046
FOV 1” (mm)	1.28 x 0.96	0.64 x 0.48	0.32 x 0.24	0.128 x 0.960

Performance (with 1X Tube lens)

Navitar industrial microscope



Optotune Module (Navitar 1-64805)
with Zoom 6000 Motorized System

Zoom system

- Modular solution for microscopy

Compatible with microscopy objectives

- Up to 50x

Also suitable for fixed magnifications

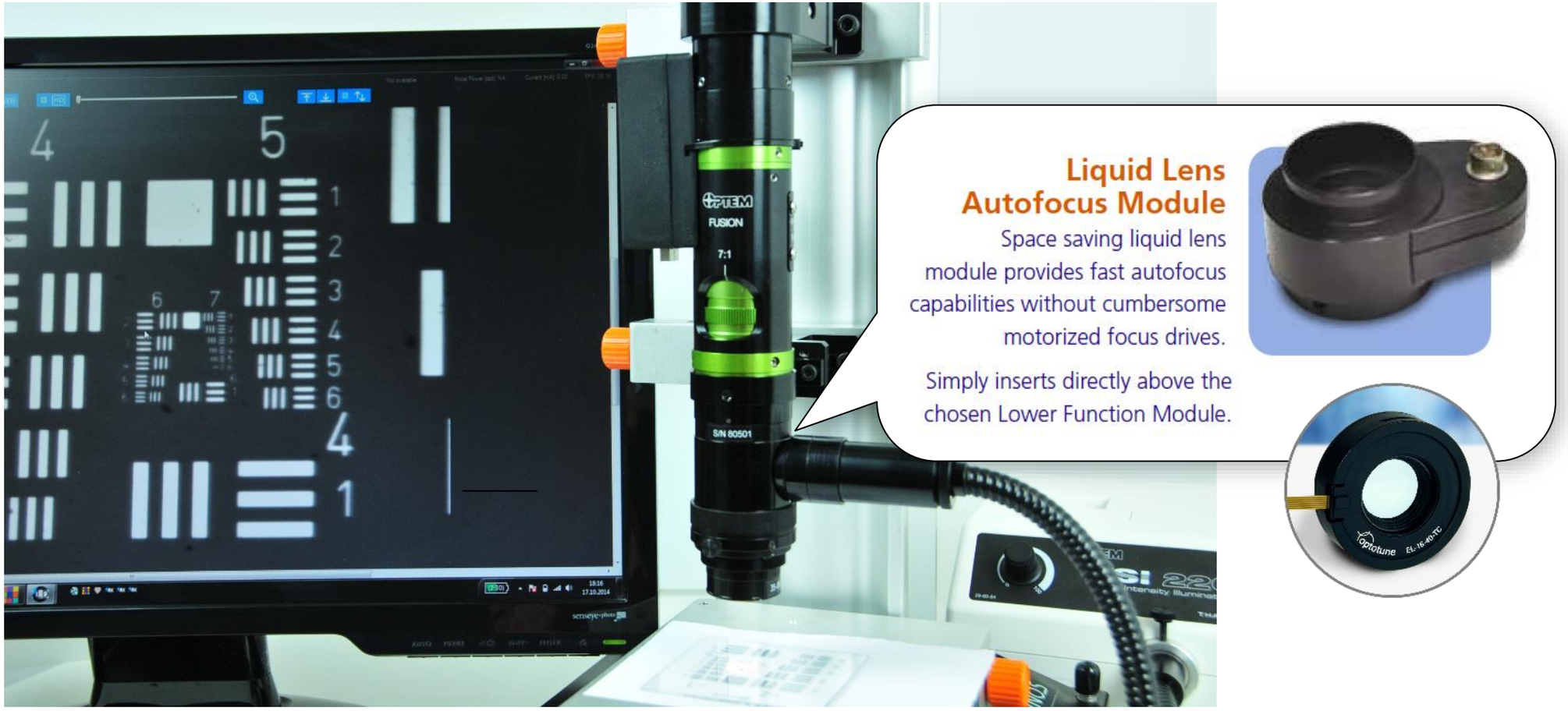
System diagram & detailed spec sheet available:

- https://navitar.com/products/imaging-optics/optotune-module/optotune-zoom-6000-system-components/

optotune

Optem Fusion industrial microscope

- Modular system for zoom or fixed mag applications
- Zoom is parfocal as the EL is placed below the zoom



http://www.qioptiq.com/optem-fusion-lens, Optem® is a registered trademark of Qioptiq, Inc

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Edmund optics dynamic focus VZM with the EL-10-30-Ci-VIS-LD-MV integrated

- Very large focus range as EL is placed close to aperture stop
- The zoom is NOT parfocal, however, as the EL is placed above the zoom

Magnification settings	0.75x	1x	2x	3x	4x	4.5x
Magnification range	0.65x – 1.15x	0.9x – 1.2x	1.5x – 2.0x	2.4x – 3.0x	3.2x - 4.0x	3.7x – 4.6x
Working distance (mm)	20 – 101	20 – 100	54 – 90	75 – 90	82 – 90	84 – 90
Horizontal FOV (1/2” sensor)	9.8 – 5.6	7.1 – 5.3	4.3 – 3.2	2.7 – 2.1	2.0 – 1.6	1.7 – 1.4

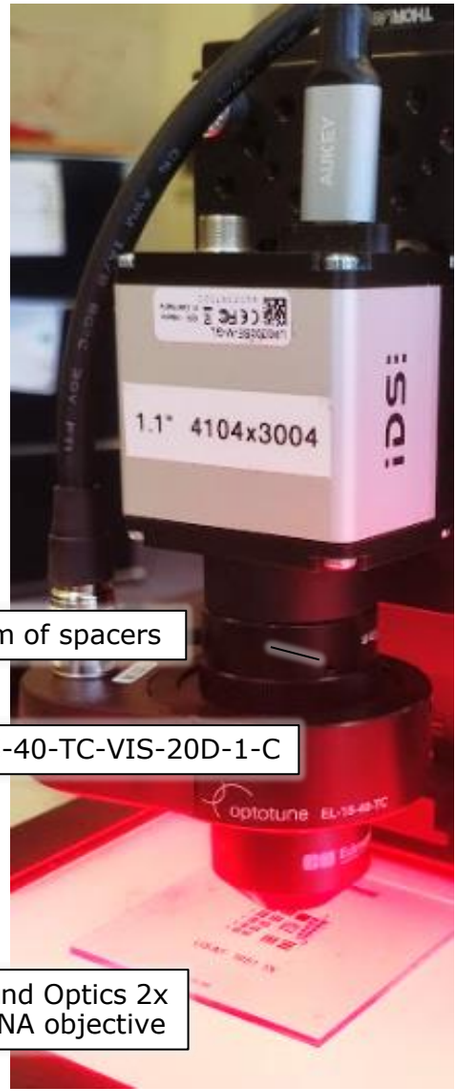
Webshop: https://www.edmundoptics.com/p/065x-46x-dynamic-focus-vzmtrade-lens/32442/

Compact variable focus 2X and 5X lenses offered by Edmund Optics

Magnification	2x	5x
		
NA	0.12	0.15
Working distance (mm)	31.3	16.2
Focus tunable range (mm)	+/- 2	+/- 0.5
Maximum sensor size	2/3”	2/3”
Field of view 2/3” sensor (mm)	4.4 x 3.3	1.8 x 1.32
Field of view 1/2” sensor (mm)	3.2 x 2.4	1.28 x 0.96
Mount	C	C
Liquid Lens	EL-10-30-Ci-VIS-LD-MV	EL-10-30-Ci-VIS-LD-MV
Edmund Optics P/N	#34-712	#34-713

Webshop: https://www.edmundoptics.com/f/tunable-compact-objective-liquid-lens-assemblies/39544/

Compact and cost effective focusing solution



High resolution

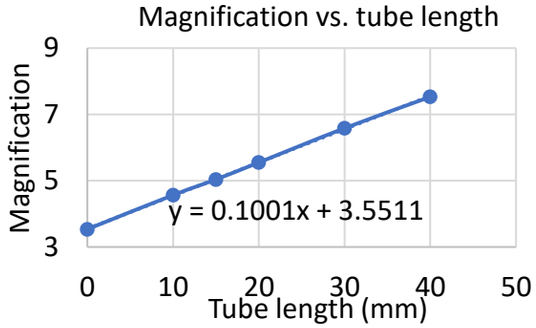
- Ideal for portable microscopy applications
- Magnification adjustable between 3x and 8x

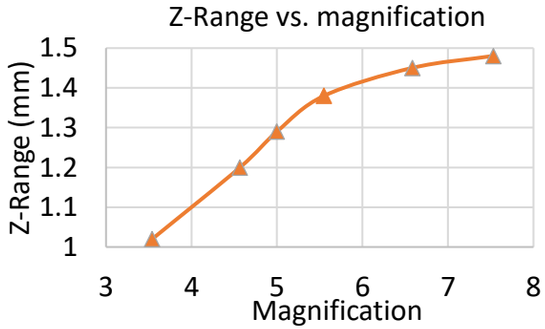
Working distance range of 1.3mm @5x

- Working distance at 0 dpt: 6.9mm
- Optical leverage of 0.065 mm/dpt

PMAG change:

- 1.3% per 100um of WD





Resources

Test report

optotune

Current solutions
To focus along Z-axis

	Motorized Z	Piezo Z	Focus Tunable Lens	
				
Price	$$	$$$	$	3x cheaper than piezo’s
Speed	+	+++	+++ (100Hz)	100x faster than motorized Z
Travel Range	+++	+	++	e.g. 600 µm with 40x objective
Compactness	+	++	+++	No table-top controller
Vibrations	+	+	+++	No vibrations
Thermal Drift	+	+	+++	Temp. comp. sensor

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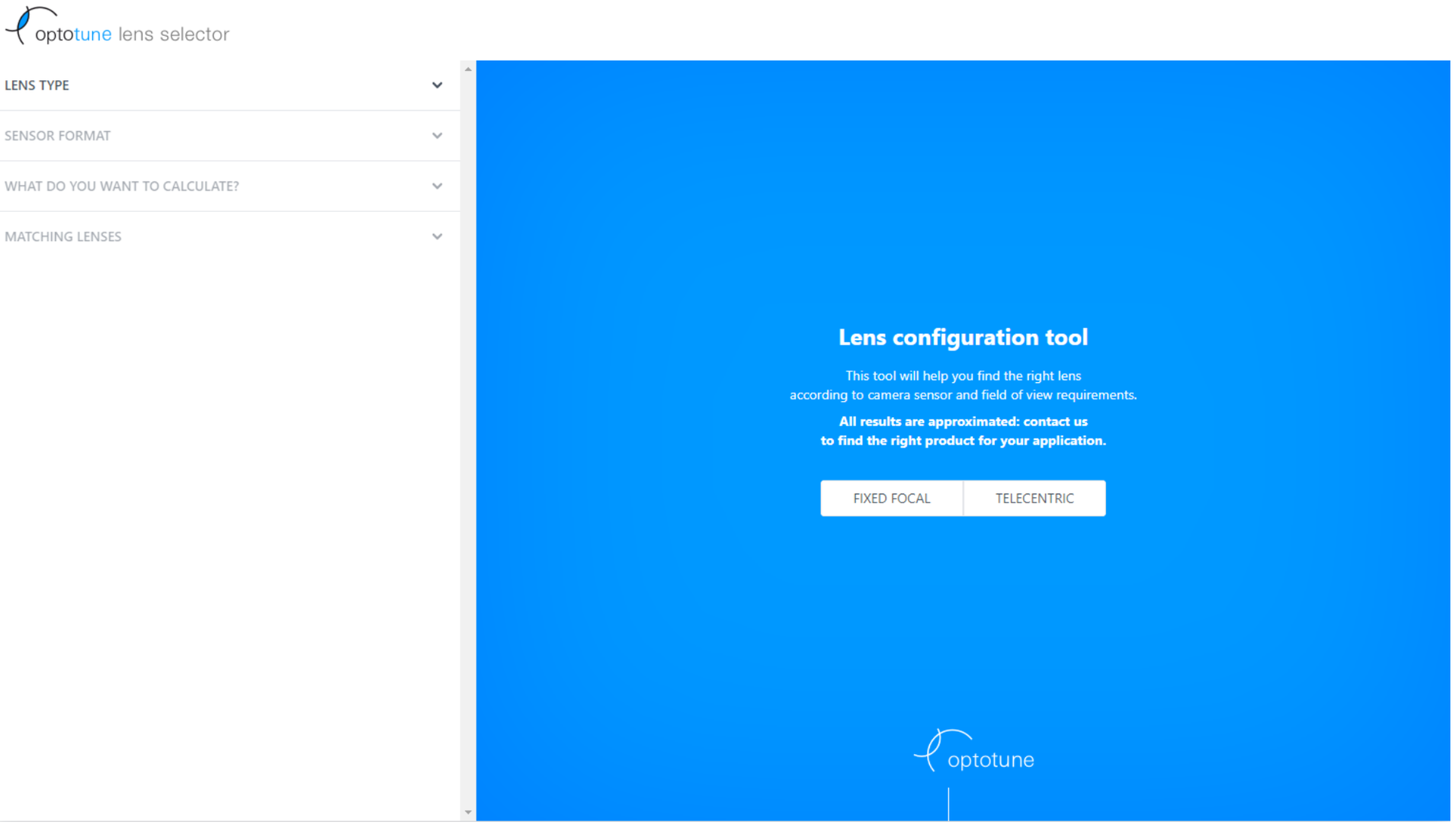
Agenda

- Introduction
- Liquid Lenses
  - Solutions for fast focusing
  - Optics configuration tools
  - Applications
- Fast Steering Devices
  - Applications
- Beam Shifting Devices
  - Applications

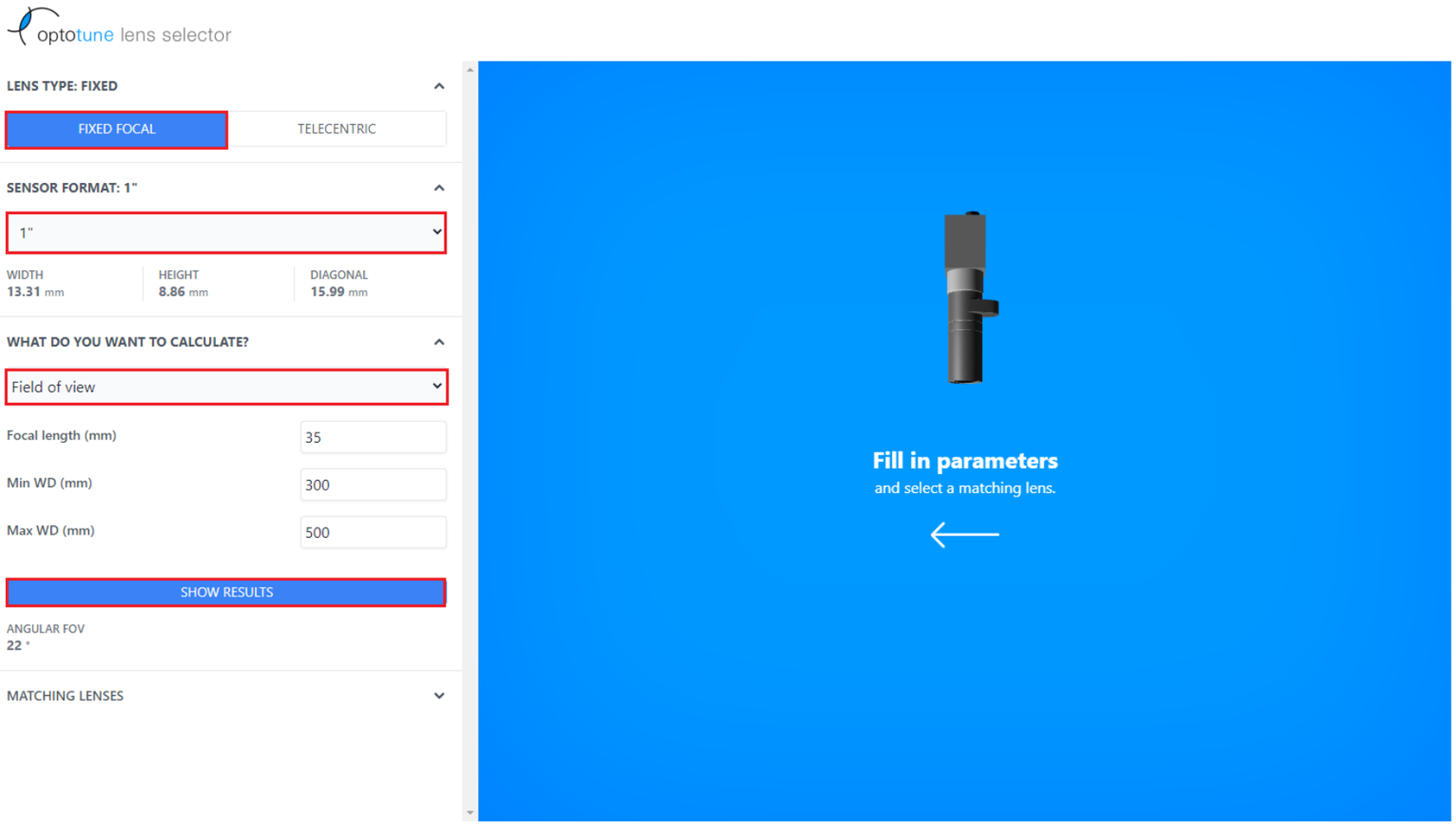
NEW Configurator: make your life easy



https://configurator.optotune.com

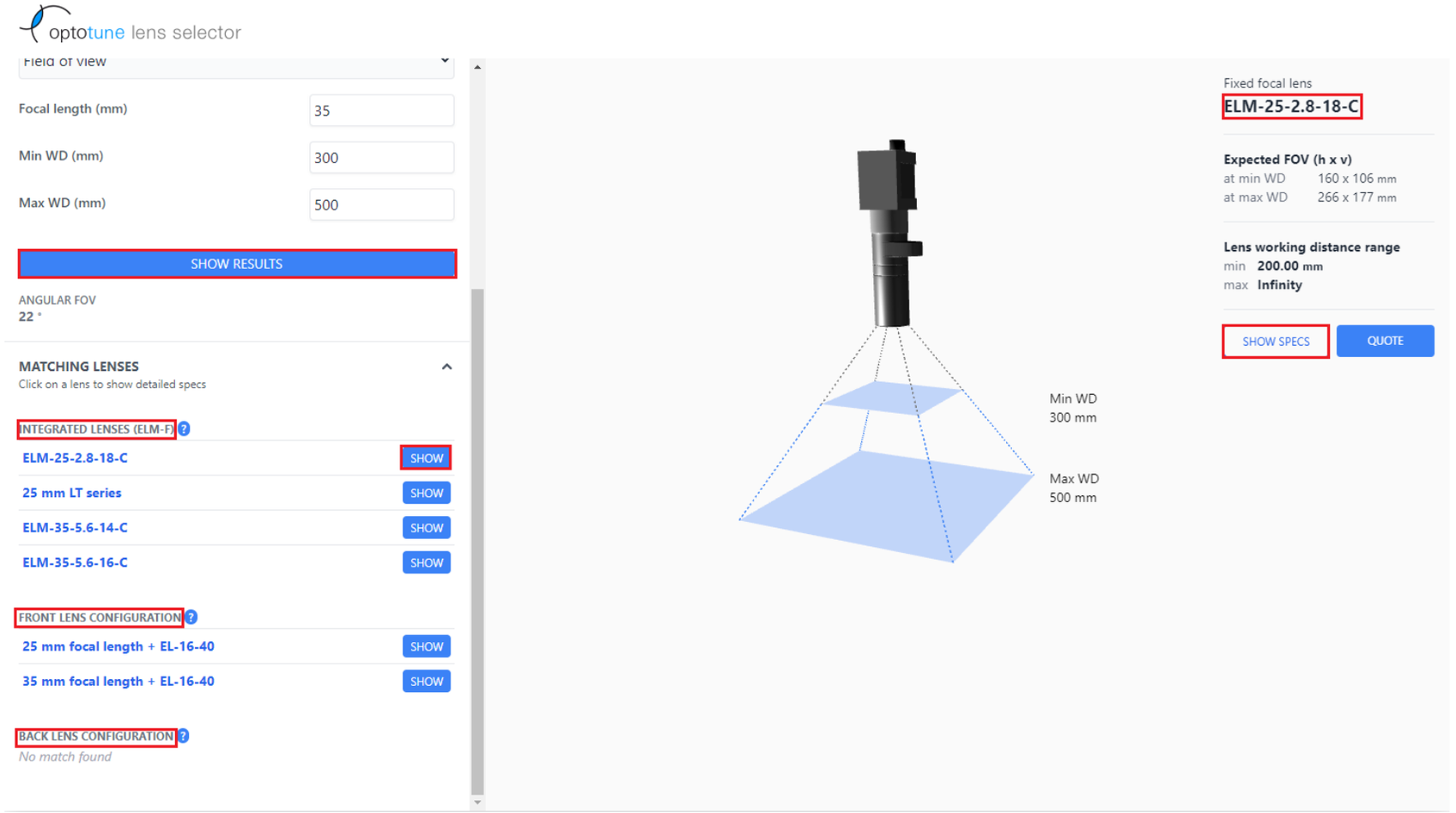
optotune

Configurator: fixed focal lenses



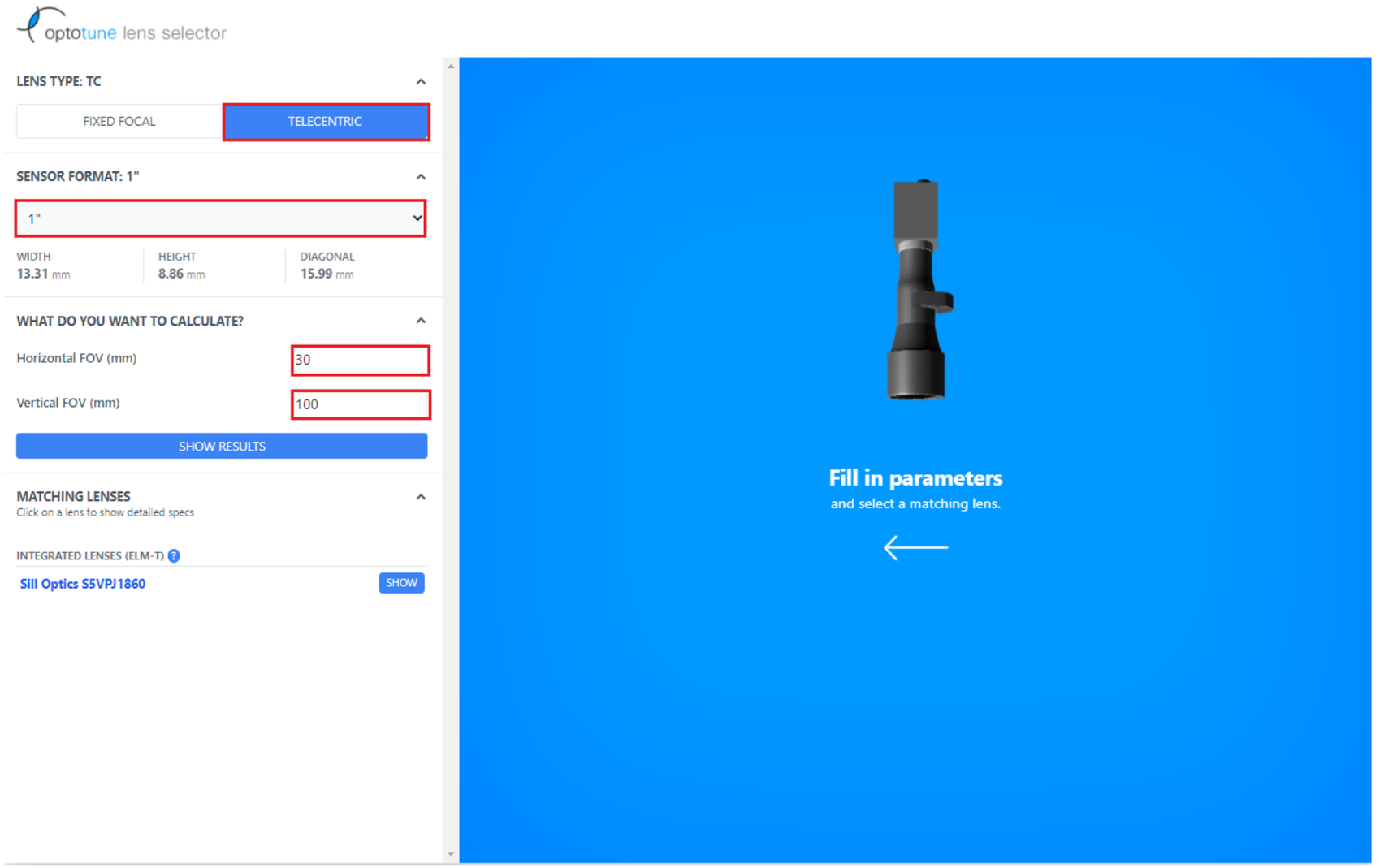
- Choose your sensor format
- Calculate field of view or focal length
- Fill the parameters
- Look at the results

Configurator: fixed focal lenses



- See available results in:
  - ELM-F
  - Front lens config.
  - Back lens config.
- Evaluate the technical specification
- Ask for a quotation
- If a standard solution is not available, ask us for a customization

Configurator: telecentric lenses



- Choose your sensor format
- Calculate your field of view
- Fill the parameters
- Look at the results

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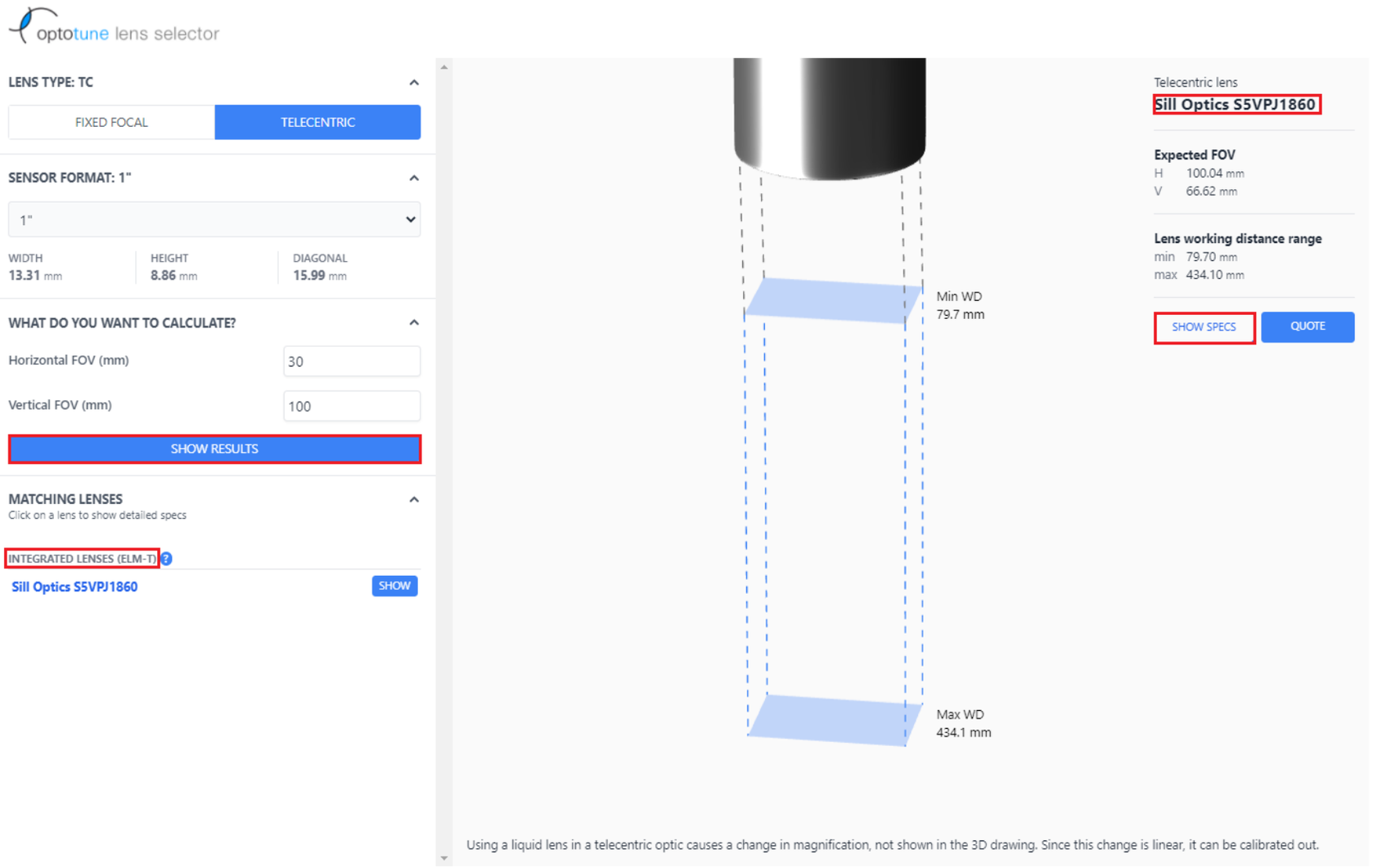
Configurator: telecentric lenses

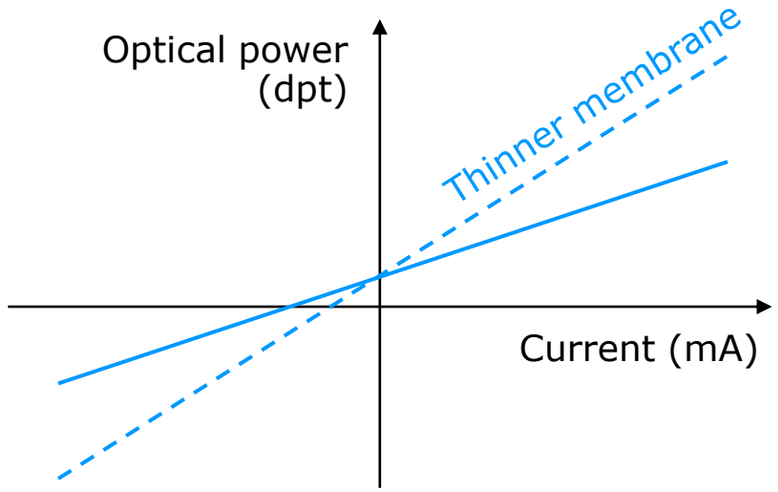


- See available results in:
  - ELM-T
- Evaluate the technical specification
- Ask for a quotation
- If a standard solution is not available, ask us for a customization

Optical power is measured in diopters

$$D = \frac{1}{f}$$

Optical power (dpt) is linear with current



- Vertical offset depends on liquid fill level
- Inclination depends on membrane stiffness

Optical power can be added arithmetically

Thin lens equation:

$$\frac{1}{f_{res}} = \frac{1}{f_1} + \frac{1}{f_2}$$

$$D_{res} = D_1 + D_2$$

Simple math in front lens configuration:

$$\frac{1}{WD_{res}} = \frac{1}{WD_0} + D_{EL}$$

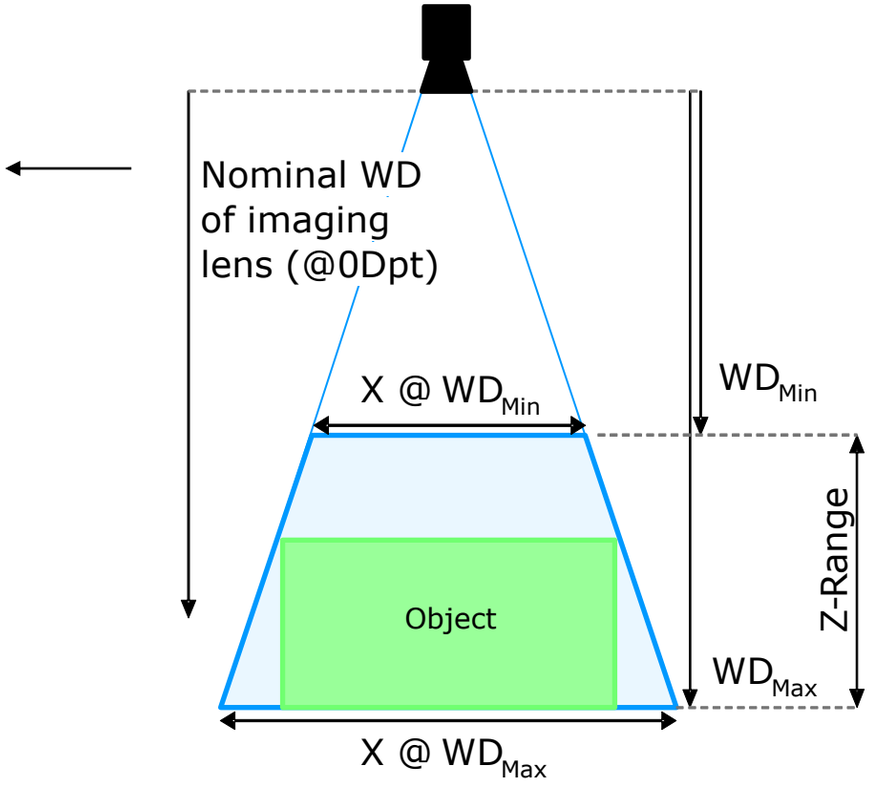
Examples:

- WD_0 = infinity, D_{EL}=5 → WD_{res} = 1/5 m
- WD_0 = 0.5m, D_{EL}=-2 → WD_{res} = infinity
- WD_0 = 0.5m, D_{EL}=3 → WD_{res} = 1/5 m

How to calculate working distance in front lens configuration

Working distances for different lens settings (mm)

Tunable lens optical power	Imaging lens WD (MOD setting, in mm)					
	100	200	300	500	1'000	∞
10	50	67	75	83	91	100
3	77	125	158	200	250	333
2	83	143	188	250	333	500
1	91	167	231	333	500	1000
0	100	200	300	500	1000	∞
-1	111	250	429	1000	∞	
-2	125	333	750	∞		
-10	∞					



$$\frac{1}{WD_{res}} = \frac{1}{WD_0} + D_{EL}$$

A typical configuration would be to set the imaging lens to 0.5m so that the WD can range from infinity to 200mm with Optotune's EL-16-40 going from -2 to +3 diopters, respectively

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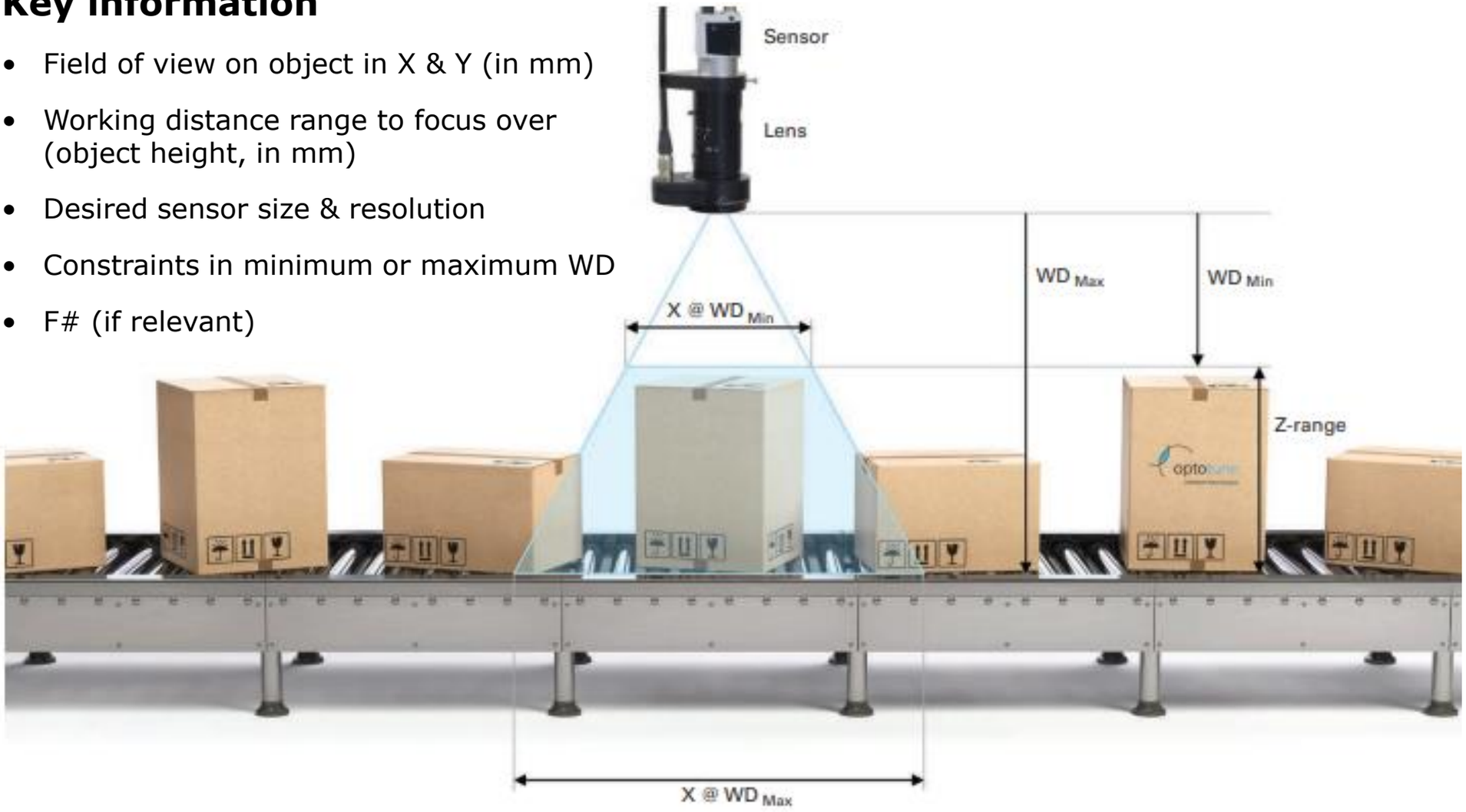
How can we support you?

Key information

- Field of view on object in X & Y (in mm)
- Working distance range to focus over (object height, in mm)
- Desired sensor size & resolution
- Constraints in minimum or maximum WD
- F# (if relevant)



Agenda

- Introduction
- Liquid Lenses
  - Solutions for fast focusing
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  - Applications
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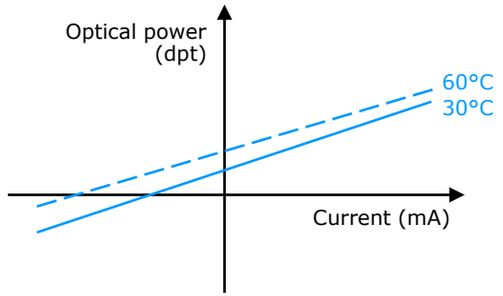
Stable focus control with temperature feedback

- Temperature drift of -0.01 to +0.03 diopters / °C (depending on lens model) is compensated by the controller
- Typical accuracy is ± 0.03 diopter, which is usually within depth of field



Set tunable lens to operate at 1 diopter

Driver reads calibration table and temperature on the lens

Temperature control feedback loop

Integrated temperature sensor with calibration data

1 diopter

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Lens control by camera removes the need for external drivers

Lens controlled by external driver

USB or Ethernet

Driver SDK

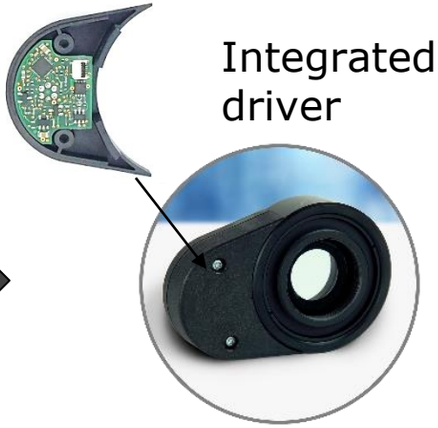
Lens current & I2C

Lens controlled via camera

Camera SDK

Any interface

Power &
Serial interface



In progress: Camera interface & firmware for focus control

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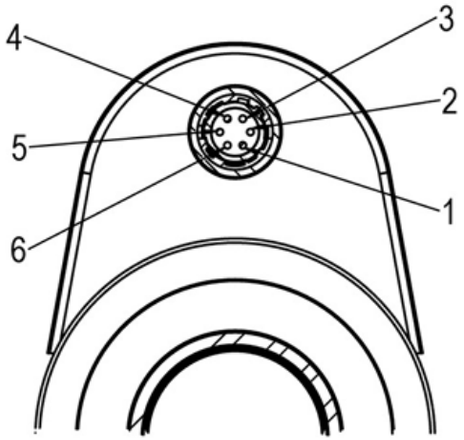
Specifications of integrated controller ECC-1C

- Serial interfaces: I2C or UART (autodetect)
- 5-24V power supply for at least 0.5W
  - Ideal would be 1.5W (e.g. 5V & 300mA)
- Connector pinout (HR10G-7R-6SB):



Pin out Hirose connector HR10G-7R-6SB(73)		
Position	**Function**	**Value**
1	GPIO Trigger	-
2	Analog In	0-10V
3	UART Tx / I^2C SCL	TTL
4	UART Rx / I^2C SDA	TTL
5	GND	-
6	VCC	5-24V

Documentation:

- Website: https://www.optotune.com/ecc-1c
- Datasheet: https://www.optotune.com/s/Optotune-ECC-1C.pdf
- Communication protocol: https://www.optotune.com/s/ECC-1C-Firmware-Documentation.zip

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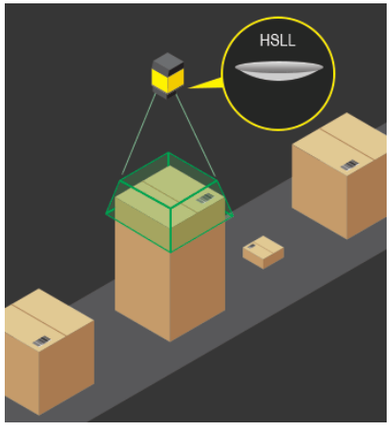
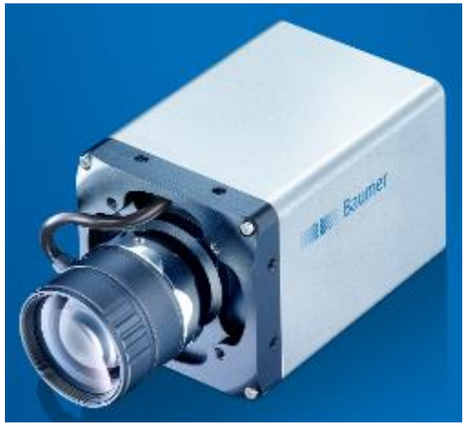
Examples of liquid lens integration



COGNEX

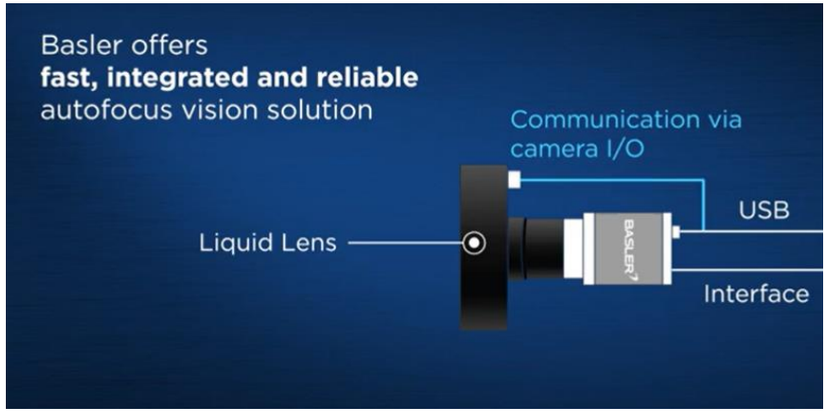


Baumer

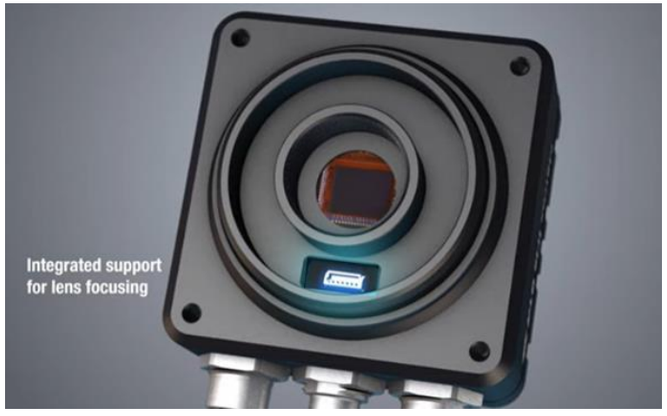
IDS

Pixelink
AMETEK

BASLER



MATROX IMAGING

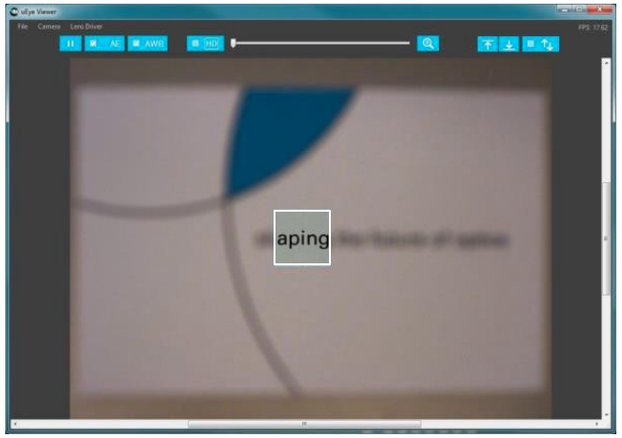


OPTO ENGINEERING

optotune

How to find the right focus

Image based autofocus

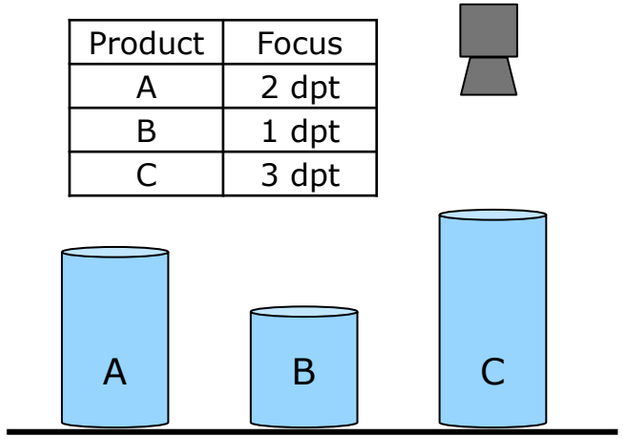


- Multiple images are acquired to find the best focus by algorithm
- Typically 10-15 frames required
  → 0.5 to 1 sec focus time

Cheap, flexible but not 100% reliable

Preset lookup tables

Product	Focus
A	2 dpt
B	1 dpt
C	3 dpt

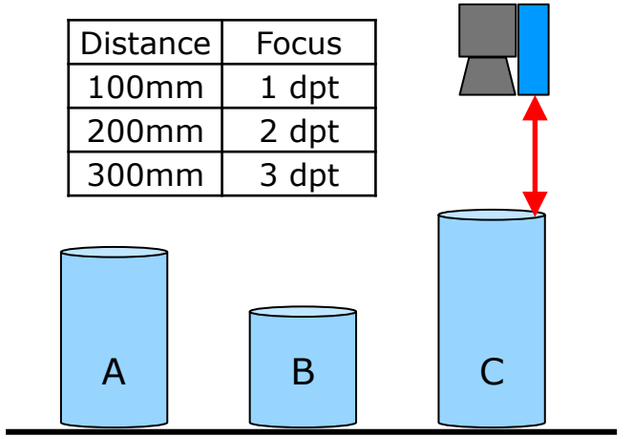


- Focus positions are stored in a lookup table during calibration (teaching)
- Only one focus step required
  → 15ms focus time

Inflexible, as reliable as the focal power mode (~0.1dpt)

Using a distance sensor

Distance	Focus
100mm	1 dpt
200mm	2 dpt
300mm	3 dpt



- Multiple distance vs focal power points are saved during calibration
- Only one focus step required
  → 15ms focus time

Flexible, quite reliable but expensive

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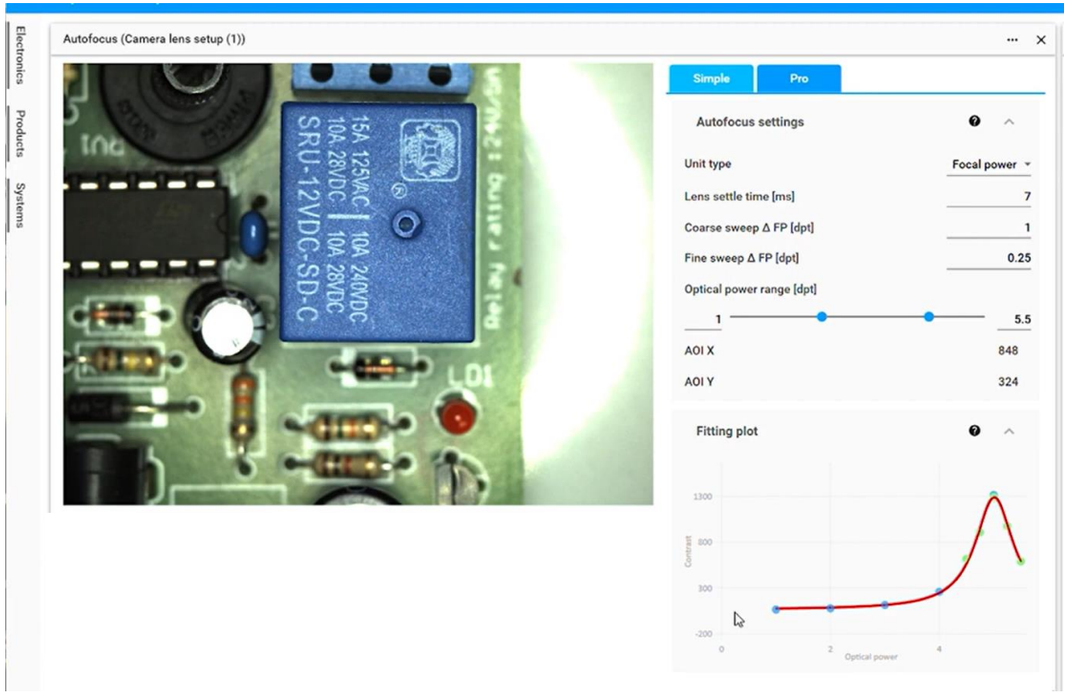
Optotune Cockpit with fast autofocus

- Optotune provides software to control all its products supporting several controllers
- Live camera images can be shown with any GenICam camera
- Autofocus is available with variable parameters to achieve best focus in typically 0.5s



For maximum speed:

- Minimize focal power range
- Adjust step sizes based on depth of field so that about 2-3 blue points and 4-6 green dots are on the peak
- Try out shorter settling times
- Reduce AOI and exposure time for AF images (and take final image in full quality)

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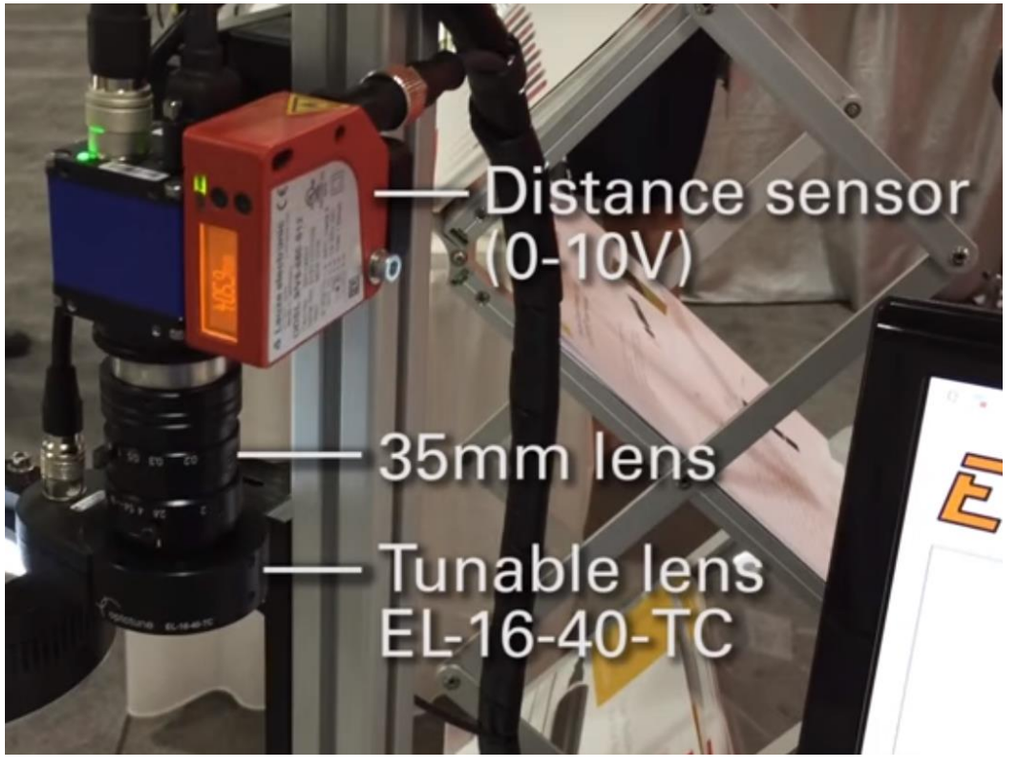
Example with distance sensor & Gardasoft driver



- Distance sensor signal is mapped to optical power
- Stand-alone system using Gardasoft TR-CL180 lens controller
- Each package is in focus within 20ms
- → at 5m/s packages can be placed with 100mm gaps

Videos available online: https://youtu.be/83mTQu9dPc8 and https://youtu.be/h5BUsn4UTNU

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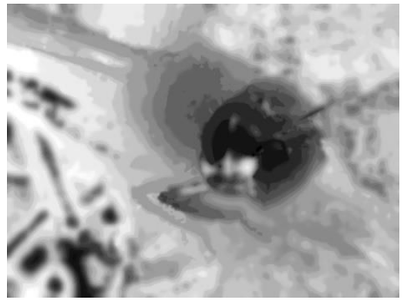
Focus stacking enables “hyper-focus” images and “depth from focus”

Z-stack of e.g. 10 to 30 images*

*Ideally the number of frames to acquire is = Z-range / DoF

Rendered hyper-focus image**



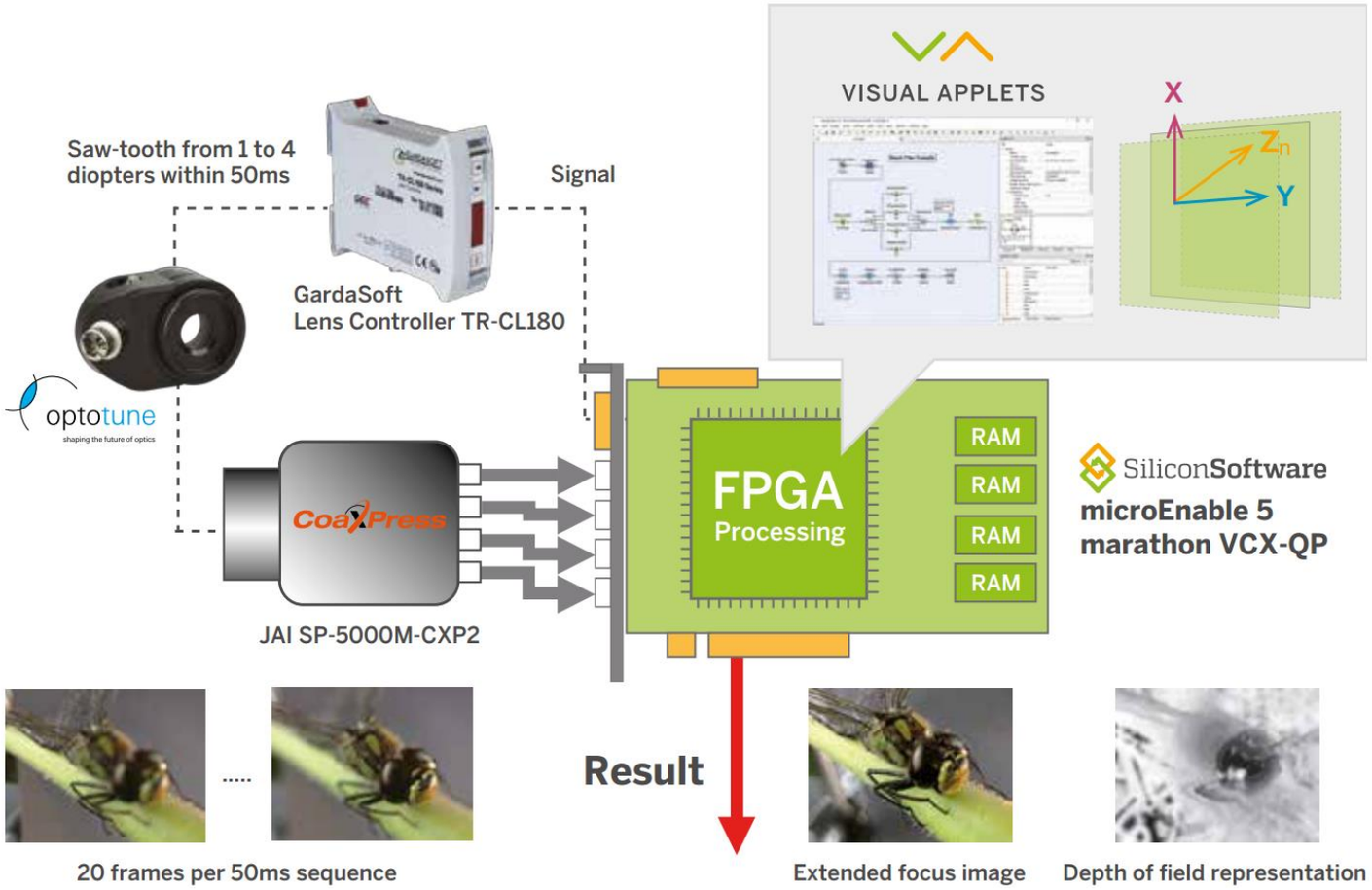
Depth map

Video

**Rendered with Helicon Focus 6.7.1 software from 15 pictures (offline)

Focus stacking in real-time using FPGA

- 20 images per stack in 50r
- Scaled & combined in FPGA
- 1MP extended depth image
- The bottle neck is now the



See demo video: https://youtu.be/-NBXIMhBlUQ

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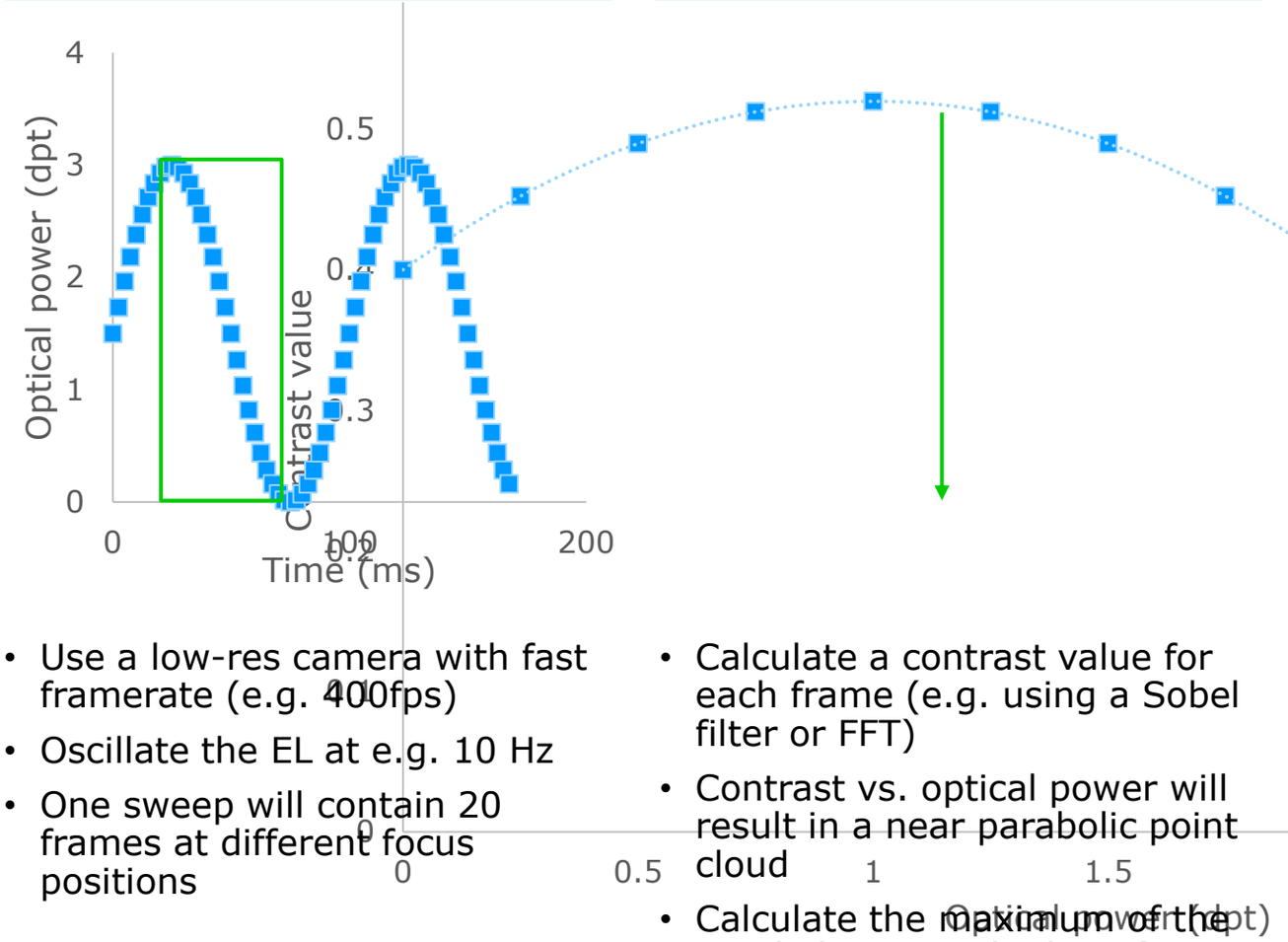
How to design a distance sensor based on DFF

1) Lens oscillation

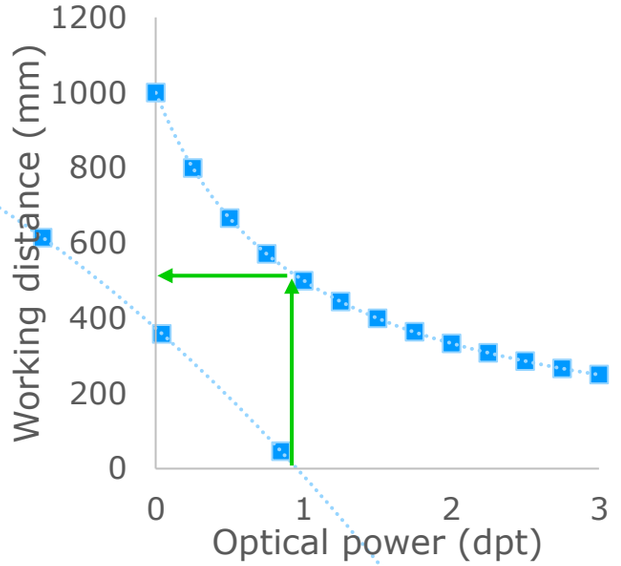
- Use a low-res camera with fast framerate (e.g. 400fps)
- Oscillate the EL at e.g. 10 Hz
- One sweep will contain 20 frames at different focus positions

2) Best focus position



- Calculate a contrast value for each frame (e.g. using a Sobel filter or FFT)
- Contrast vs. optical power will result in a near parabolic point cloud
- Calculate the maximum of the parabola to get the best focus position

3) Match related distance



- Get the corresponding working distance from a pre-calibrated lookup table
- Relation can be linear (telecentric lenses, microscope objectives) or 1/x (front lens configuration)

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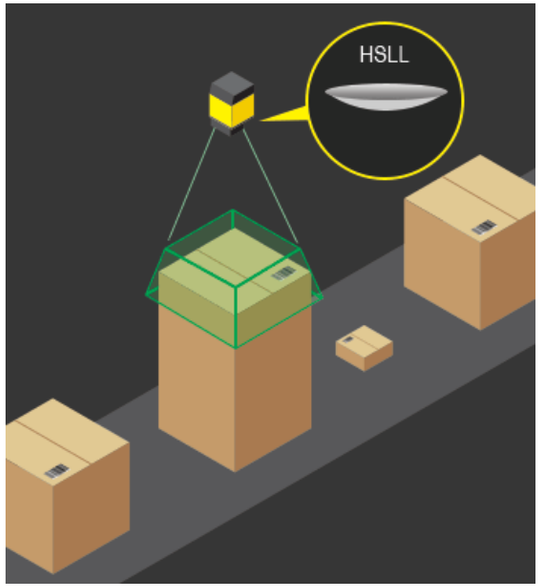
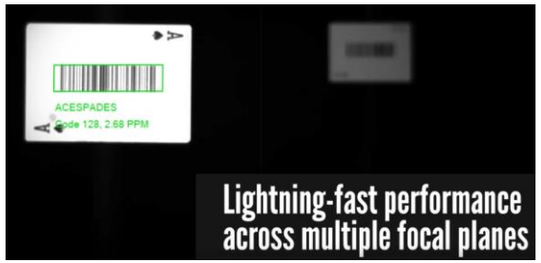
Application example: 2D code reading

Working distance expansion with EL-3-10

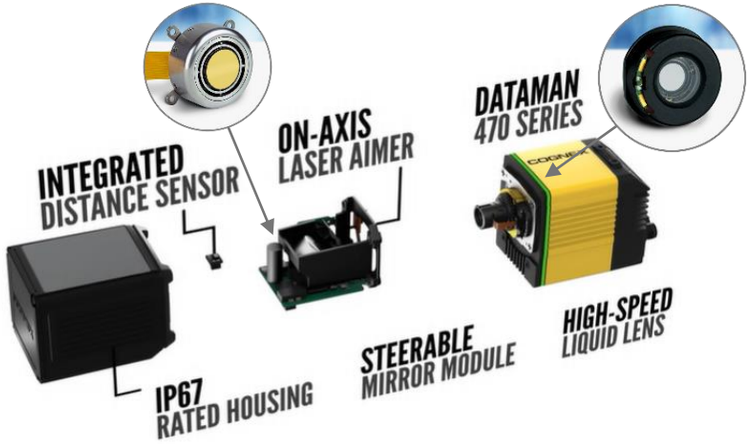


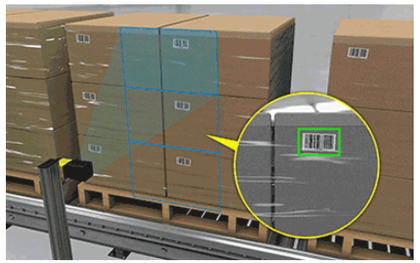


https://www.cognex.com/products/leading-technology/liquid-lens-technology

https://www.youtube.com/watch?v=dGSpB4WGlc4

Field of view expansion with MR-15-30





https://www.cognex.com/products/leading-technology/high-speed-steerable-mirror

optotune

Application example: Package sorting

Setup

- Code reading and OCR on boxes of different heights
- Sensor size: 40mm (line scan)
- Tunable lens: EL-16-40-TC-VIS-5D-M42
- Imaging lens: 60mm M42-mount
- Angular FOV: 37°
- WD range: 800 – 1500mm

Advantages

- Extended Z-range: 700mm
- Fast refocus on barcodes
- Long lifetime

Application example: Bottle inspection

Camera

Fixed focal length lens

EL-16-40

Setup

- Inspection of bottle bottom, variable sizes
- Sensor size: 2/3”
- Imaging lens: 35mm C-mount
- Tunable lens: EL-16-40-TC-VIS-5D-M27
- Angular HFOV: 14°
- WD range: 150 to 550mm

Advantages

- Extended Z-range: 400mm
- Fast refocus at different heights
- Vibration free

optotune

Application example: Robotic vision inspection

Setup

- Camera mounted on robot arm
- Sensor size: 1/2”
- Imaging lens: 12mm S-mount
- Tunable lens: EL-10-30-Ci-VIS-LD-MV
- Angular HFOV: 30°
- WD range: 170 to 1000mm

Advantages

- Extended Z-range: 830mm
- Compact & light-weight
- Variable magnification, e.g. reducing WD from 1m to 0.2m + refocusing results in a 5X zoom!

Application example: Contact lens inspection

Camera

EL-16-40

Fixed focal length lens

Setup

- Inspection of contact lenses (defects, read imprinted codes)
- Sensor size: 2/3”
- Tunable lens: EL-16-40-TC-VIS-5D-C
- Imaging lens: 50mm C-mount
- FOV: 28x21mm

Advantages

- Extended Z-range: 45mm
- Focus along curved surfaces
- High repeatability

Application example: Electronic inspection

Setup

- Inspection of electronics
- Sensor size: 1”
- Tunable lens: EL-16-40-TC-VIS-5D-C
- Imaging lens: 50mm C-mount
- FOV: 40x30mm

Advantages

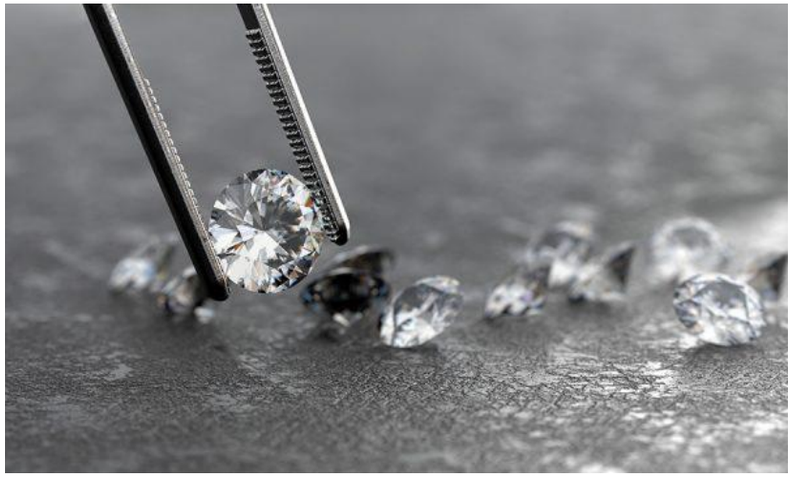
- Extended Z-range: 45mm
- Continuous focus
- Plug & play solution

Application example: Jewel inspection

Camera

EL-16-40

Fixed focal length lens



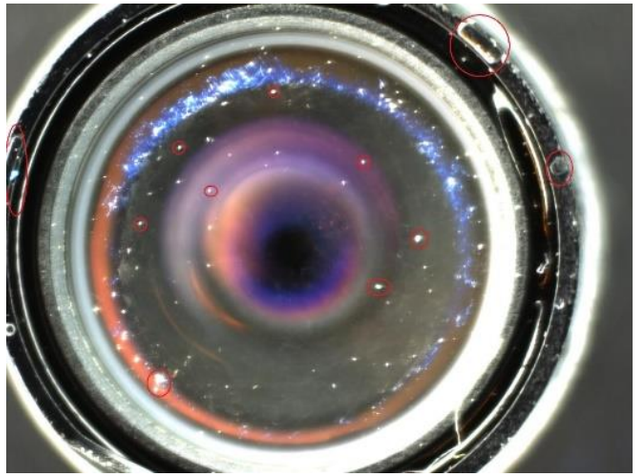
Setup

- Defect identification
- Sensor size: 1”
- **Distance rings: 20mm**
- Tunable lens: EL-16-40-TC-VIS-5D-C
- Imaging lens: 50mm C-mount
- FOV: 24x18mm

Advantages

- Extended Z-range: 21mm
- Fast focus
- Vibration free

Application example: Camera lens inspection



Setup

- Inspection of dust & scratches in a stack of molded plastic lenses
- Sensor: 1.1” 12MP
- Imaging lens: 1.0X telecentric VS-THV1-110_S-LQL1
- Tunable lens: EL-16-40-TC-VIS-5D-C
- FOV: 14.2x10.4mm

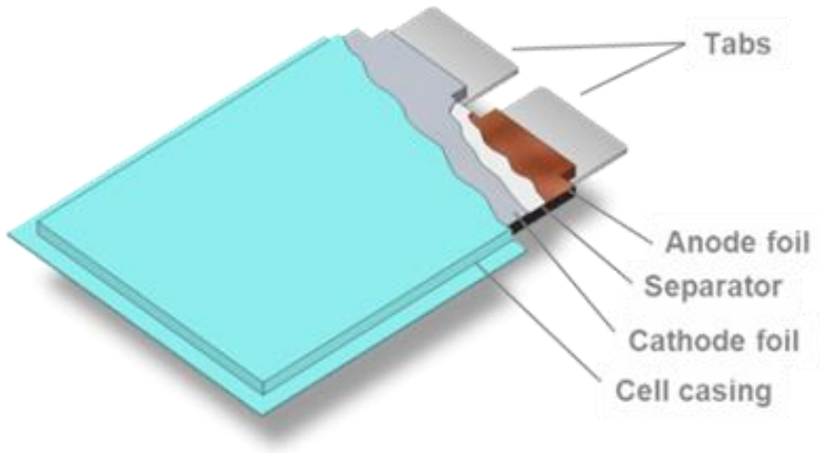
Advantages

- Extended Z-range: 14.3mm
- Fast focus
- Vibration free

Resources

Test report available: https://www.optotune.com/s/181010-VS-THV1-110-LQL1-EL-16-40-TC-VIS-5D-C.pdf

Application example:
Battery inspection – focus on different layers



Setup

- Focus on each battery layer for quality inspection
- Sensor size: 2/3”
- Tunable lens: EL-16-40-TC-VIS-5D-C
- Imaging lens: 1x Telecentric lens
- WD range: 150 - 170mm

Advantages

- Vibration free
- High repeatability
- Long lifetime

Application example: Particles counting

Setup

- Focus on 6 probes to count crystals in liquid
- Sensor size: 2/3”
- Tunable lens: EL-16-40-TC-VIS-5D-C
- Imaging lens: 2x, 4x, 6x Telecentric lens
- WD range: 110 – 120mm

Advantages

- Extended DOF for high magnification
- Focus can sweep across liquid
- Vibration free

Application example:
Pick&place robot – EC inspection

Setup

- Focus on different electronic components on a board inspection
- Sensor size: 1/2”
- Tunable lens: EL-3-10-VIS-26D-TS
- Imaging lens: Custom developed telecentric lens
- WD range: 150-160mm

Advantages

- Extended DOF
- Fast focus
- Linear and repeatable magnification change

Application example:
Quality inspection – micropipette

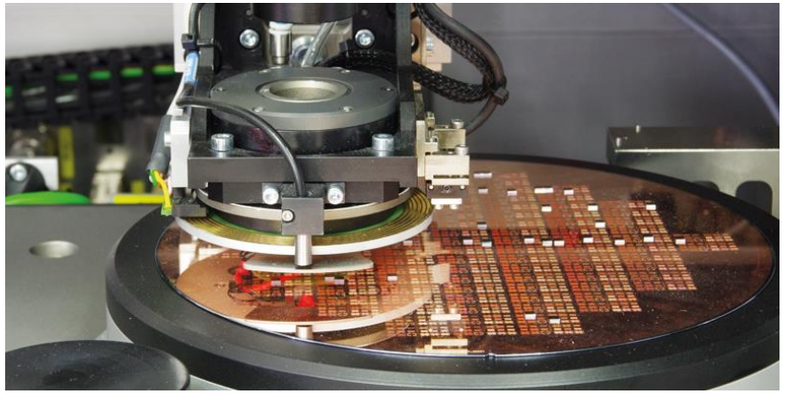
Setup

- Top & bottom pipette inspection
- Sensor size: 1/2” & 2/3”
- Tunable lens: EL-16-40-TC-VIS-5D
- Imaging lens: 0.5X and 2x telecentric lens
- WD range: 150-180mm

Advantages

- FOV expansion with MR-15-30
- Extended DOF
- Cost effective

Application example: Die bonding



Setup

- Quality inspection over wafers
- Sensor size: 2/3”
- Tunable lens: EL-16-40-TC-VIS-5D-C
- Imaging lens: 1.5x and 3x telecentric lens
- WD range: 120-150mm

Advantages

- Extended DOF
- Fast focus
- High repeatability

Application example: Metrology

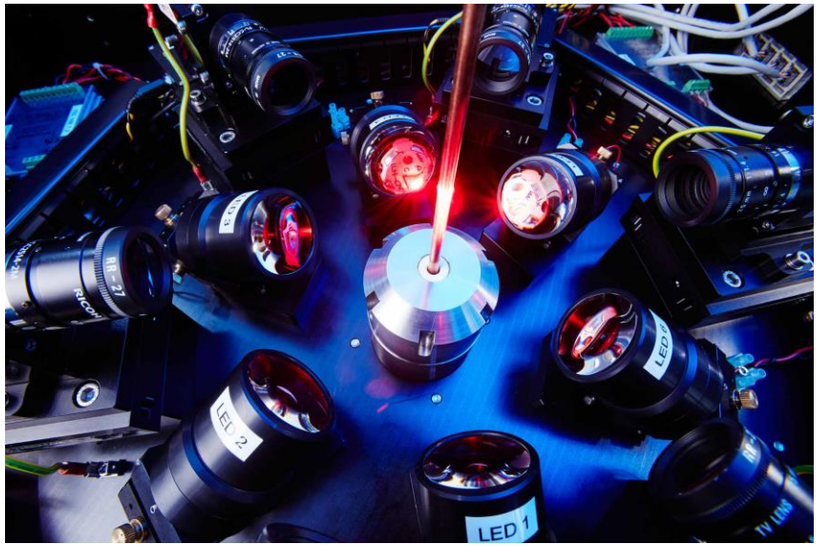
Setup

- Inspection and measurements of small parts during manufacturing
- Sensor size: 2/3”
- Tunable lens: EL-16-40-TC-VIS-5D-C
- Imaging lens: 0.36x telecentric lens
- WD range: 107 – 124 mm

Advantages

- Fast focus
- Linear and repeatable magnification change
- Simpler architecture

Application example: Cable inspection



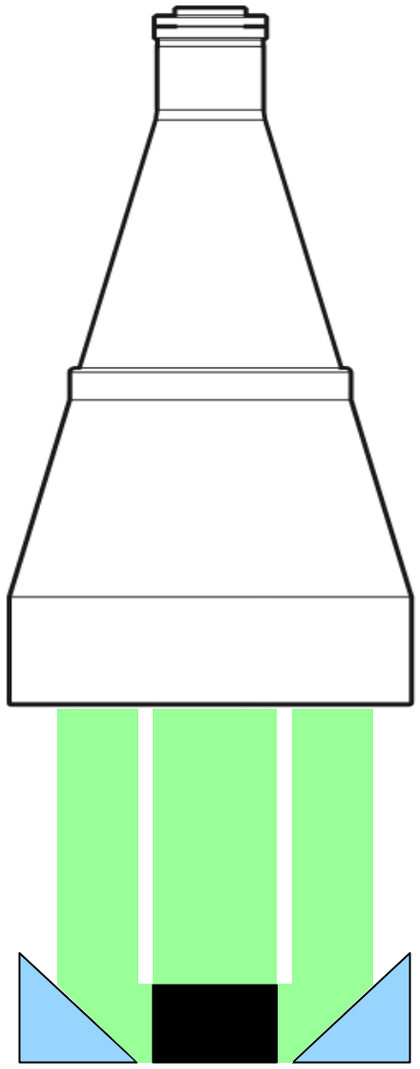
Setup

- Measurement of wire thickness and defects
- Sensor size: 2/3”
- Tunable lens: EL-16-40-TC-VIS-5D-C
- Imaging lens: 1.0x telecentric lens
- WD range: 75 – 88 mm

Advantages

- Fast focus
- Vibration free
- High repeatability

Application example: IC inspection



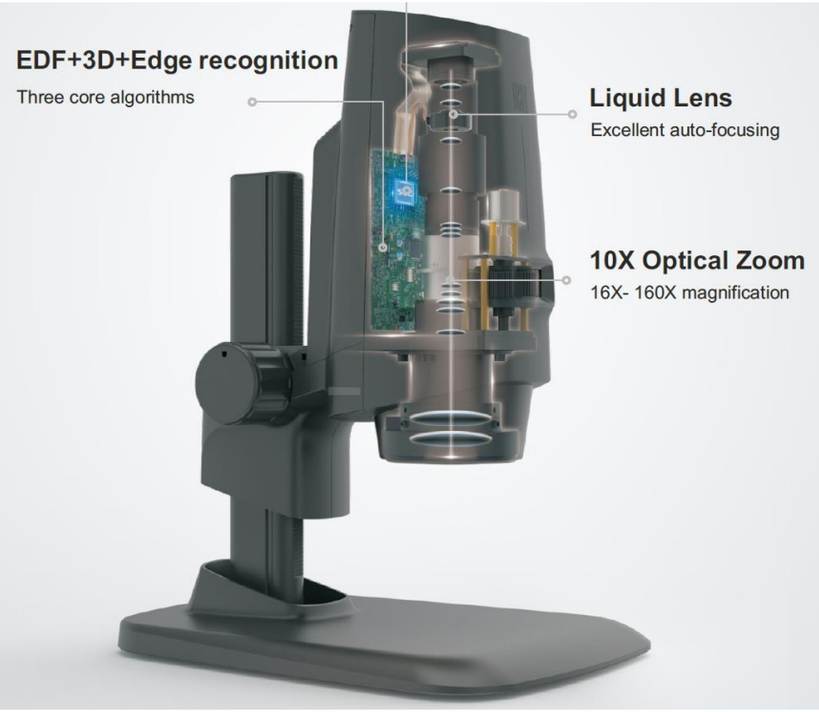
Setup

- Inspection of ICs
- Sensor: 1/2"
- Imaging lens: 0.15X telecentric lens
- Tunable lens: EL-10-30-Ci-VIS-LD (integrated)
- FOV: 41.2x30.9mm

Advantages

- Top & side view (via mirrors)
- Z-range: 50mm
- Long lifetime

Application example:
Digital microscope with EDOF and 3D mapping

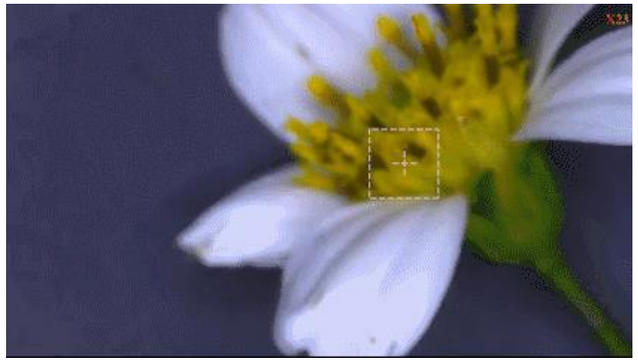


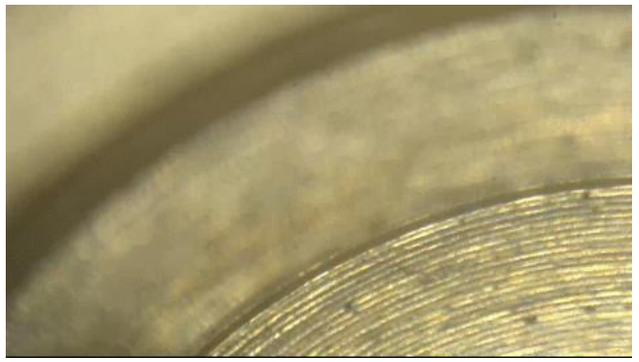
Setup

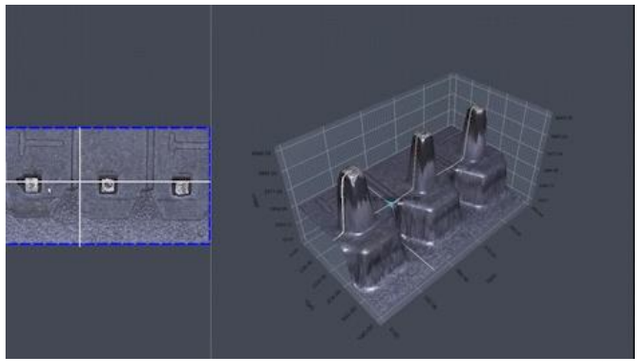
- Inspection of parts
- Tunable lens: EL-10-30-TC
- Imaging lens: 10x Optical zoom
- 3D reconstruction from image stacking

Advantages

- Automatic zoom
- Continuous focus
- Fully integrated control system







Video: https://youtu.be/5h5JyK8z_j8 Website: tucsen.com/tmetrics-t20-product

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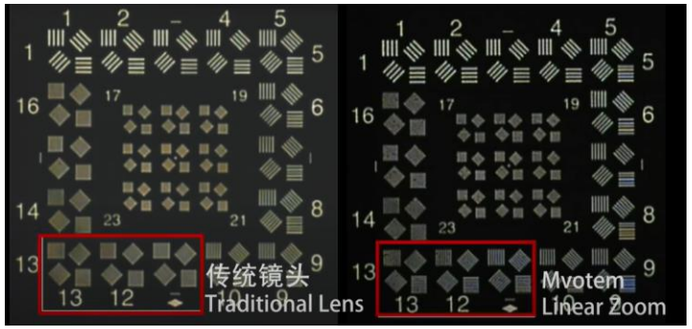
Application example:
Zoom & AF for industrial microscope



Setup

- Automated measurement system
- Tunable lens: EL-16-40-TC-VIS-5D-C
- Two zoom config.: 6.5x and 12x
- All-in-focus system

Advantages

- Automatic zoom
- Fast focus
- Vibration Free

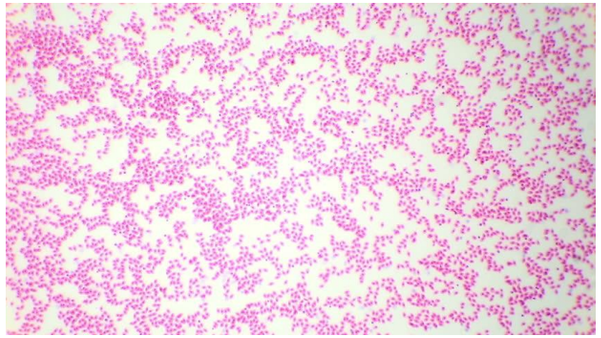
Resources

Video: https://youtu.be/ZZFe3hg9JwM

Website:www.mvotemoptics.com/automatic-zoom-lens.html

optotune

Application example:
Portable microscope - blood analysis



Setup

- Cell counting & analysis
- Sensor: 2/3"
- Empty tube: 50mm
- Tunable lens: EL-10-30-Ci-VIS-LD-MV
- Imaging lens: inverted 16mm lens (e.g. Edmund Optics 85350)
- Magnification: 6X
- FOV: 1.4x1.1mm

Advantages

- Extended Z-range: 0.8mm
- Compact & portable system
- Fast focus sweep through liquid

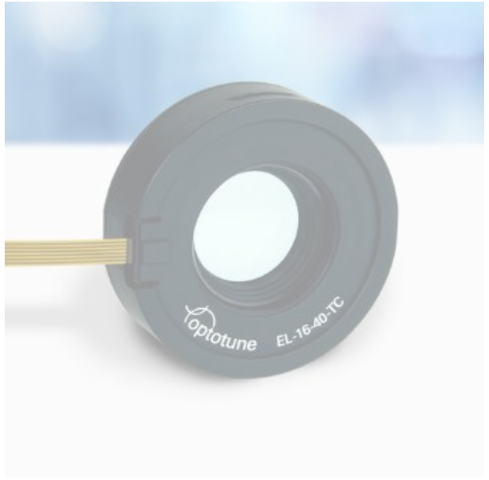
Agenda

- Introduction
- Liquid Lenses
  - Solutions for fast focusing
  - Optics configuration tools
  - Applications
- Fast Steering Devices
  - Applications
- Beam Shifting Devices
  - Applications

Product Portfolio

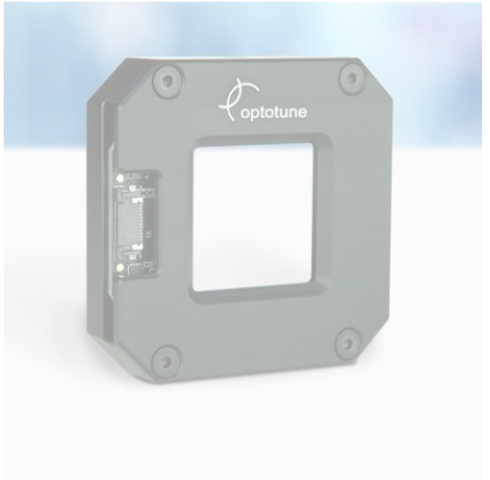
Our solutions for Machine Vision

Focus tunable lenses



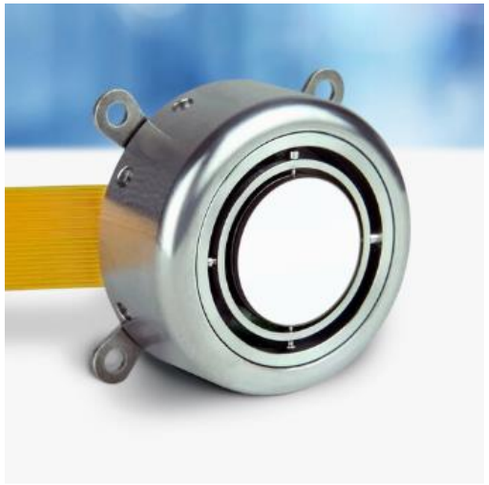
- Fast autofocus
- Fast detection
- Image stacking

Beam shifting devices

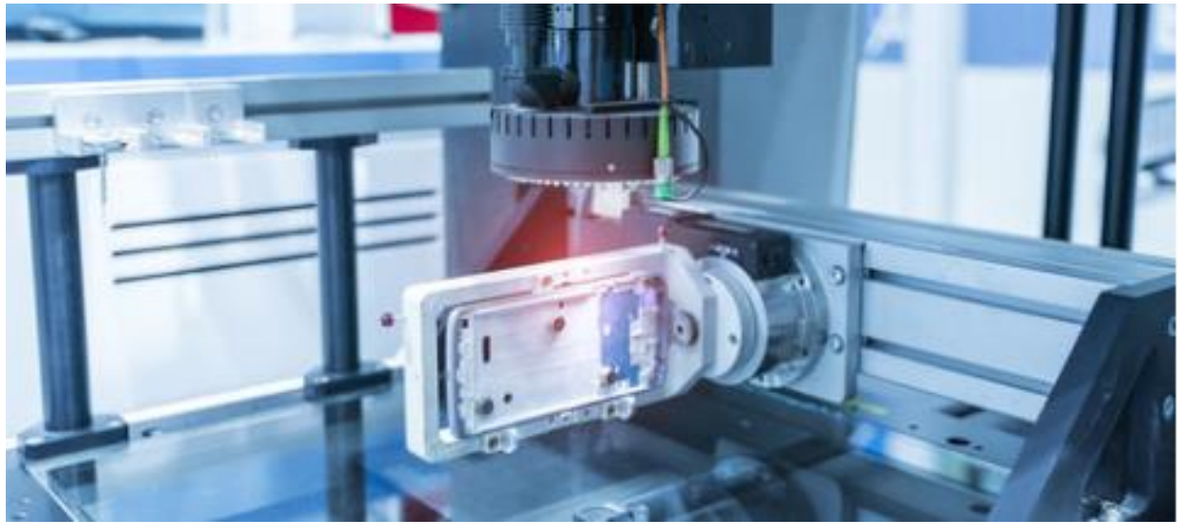


- Fast transition time
- Reliable over time
- Beam shifts up to 4.8um

Beam steering devices



- Sole reflection
- Wide angular range
- Compact



optotune

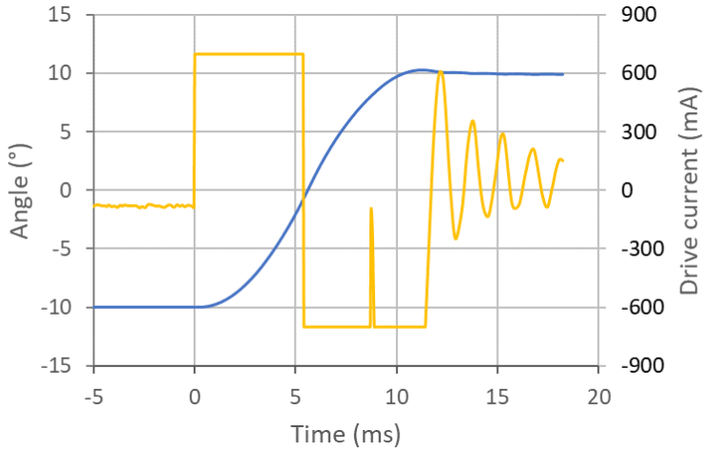
Optotune's fast steering mirrors

Specifications

- 2D deflection with a single reflective surface
- Large scanning angle of +/-25°
- Rotation point close to center of mass
- >1B cycles with robust voice-coil actuation
- High repeatability of 40 µrad (optical feedback)
- Response time of few milliseconds

Benefits

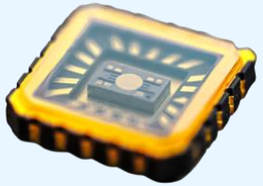
- Most compact scanning solution
- Field of view up to 100°
- Insensitive to shock & vibrations
- Long Lifetime
- Accurate closed loop control
- Vector scanning, point & shoot with high throughput



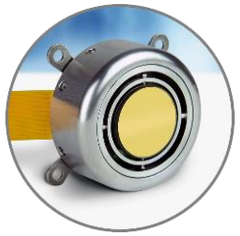
MR-15-30
Step response

optotune

Current solutions
To steer your beams

	MEMS	Galvos	Fast Steering Mirrors
			
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	40 microrad
Full stroke frequency	100-300 Hz	300-600 Hz	20 Hz

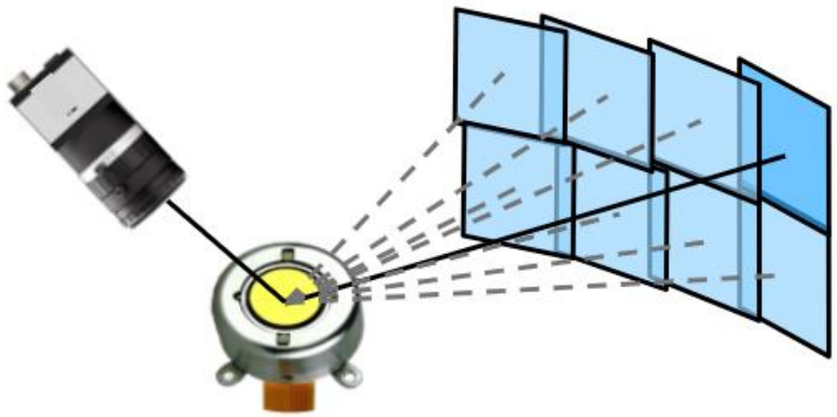
Optotune has extended its mirror portfolio

	MR-15-30	MR-10-30	MR-50 (prototype)
			
# axis	2D	2D	1D
Mirror size	∅15 mm	∅10 mm	55x50 mm^2
Mechanical tilt – 1. axis (half angle)	25°	12.5°	30°
Full-scale bandwidth – 1. axis	20 Hz	250 Hz	10 Hz (triangular)
Mechanical tilt – 2. axis (half angle)	25°	25°	--
Full-scale bandwidth – 2. axis	20 Hz	20 Hz	--
Mech. Repeatability RMS	40 µrad	40 µrad (1. axis)	600 µrad estimated
Resolution	22 µrad	22 µrad	150 µrad
Footprint	30x14.5	30x14.5	67.5 x 70 x 45
Position feedback	yes	yes	yes

Agenda

- Introduction
- Liquid Lenses
  - Solutions for fast focusing
  - Optics configuration tools
  - Applications
- Fast Steering Devices
  - Applications
- Beam Shifting Devices
  - Applications

Application example: Area of interest selection/inspection



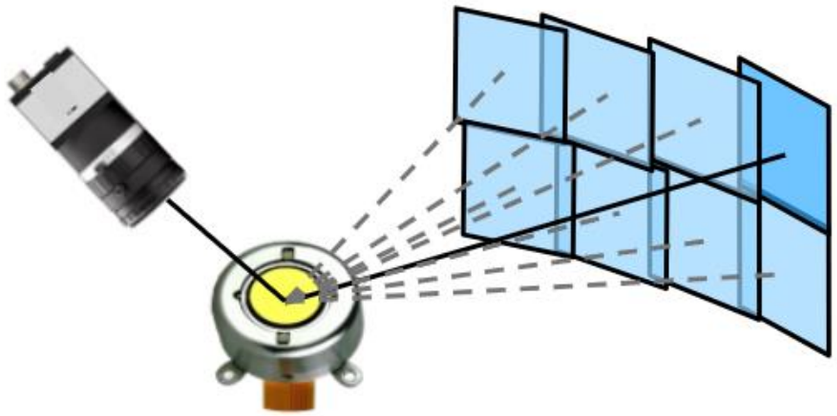
Setup

- Sensor: 1/1.8"
- Tunable lens: EL-16-40-TC-VIS-5D
- Imaging lens: 50mm or 75mm
- FOV: 67° x 84°

Advantages

- Select small FOV within large FOV
- Use inexpensive image sensor
- High angular resolution
  (6 mdeg with 50mm lens)

Application example: Image stitching



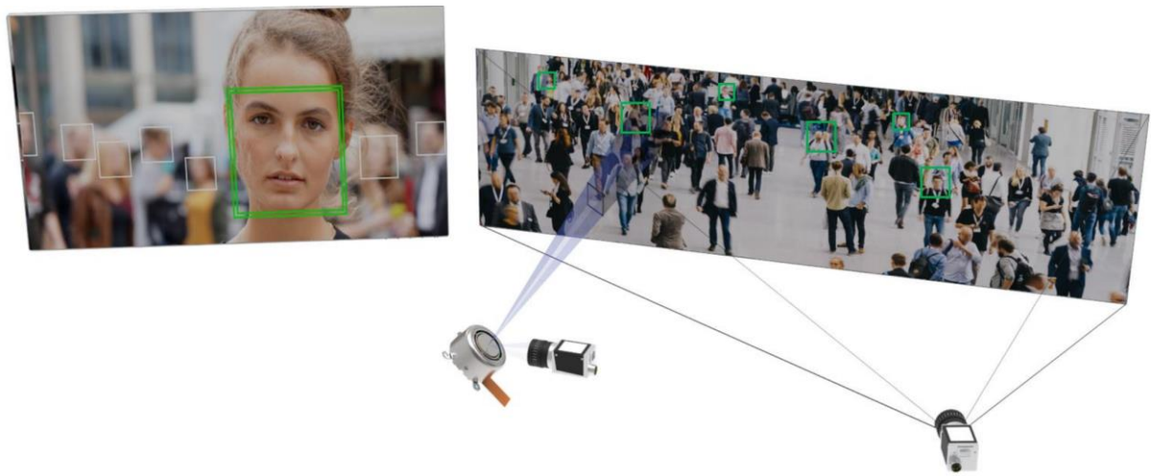
Setup

- Sensor: 1/1.8"
- Tunable lens: EL-16-40-TC-VIS-5D
- Imaging lens: 50mm or 75mm
- FOV: 67° x 84°

Advantages

- Gigapixel resolution
- Faster than motorized gimbal solutions
- Compact & reliable

Application example: Surveillance



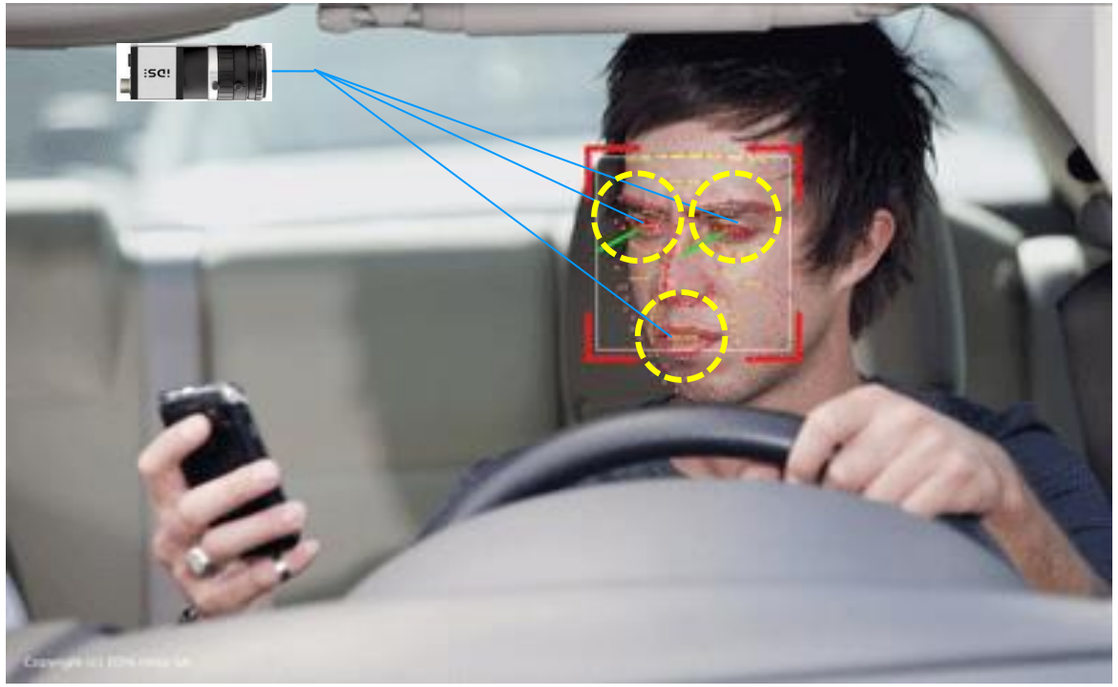
Setup

- Sensor: 1/1.8"
- Tunable lens: EL-16-40-TC-VIS-5D
- Imaging lens: 50mm or 75mm
- FOV: 67° x 84°

Advantages

- "Zoom in" on details
- High angular resolution
  (6 mdeg with 50mm lens)
- Recognize faces within large distance
  (e.g. airport hall)

Application example: Driver attention monitoring



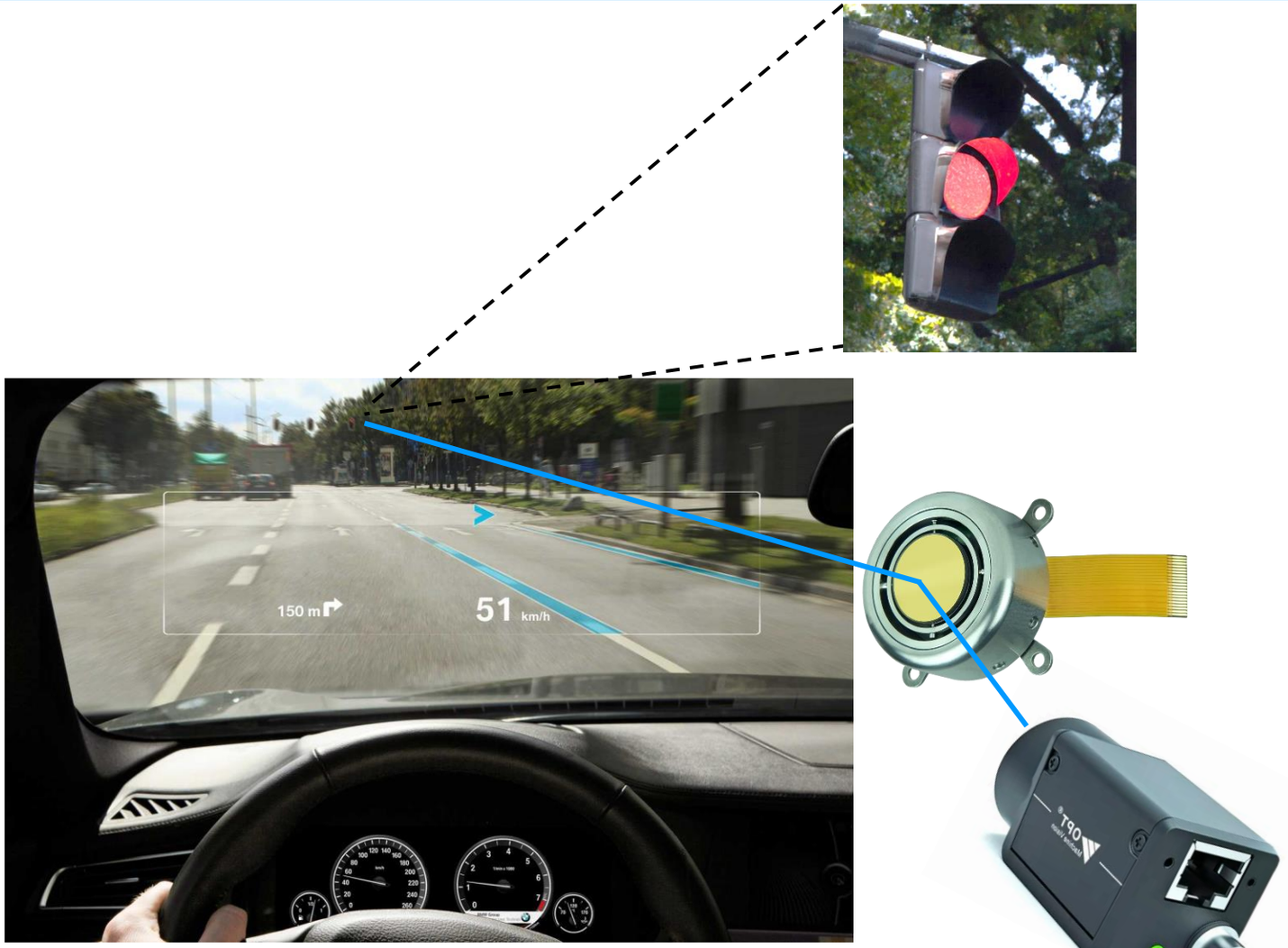
Setup

- Sensor: 1/1.8"
- Tunable lens: EL-16-40-TC-VIS-5D
- Imaging lens: 50mm or 75mm
- FOV: 67° x 84°

Advantages

- Drowsiness detection
- "Zoom-in" on eyeball (AOI)
- Adapt to different driver heights
- Switch between multliple AOIs

Application example: Traffic sign monitoring



Setup

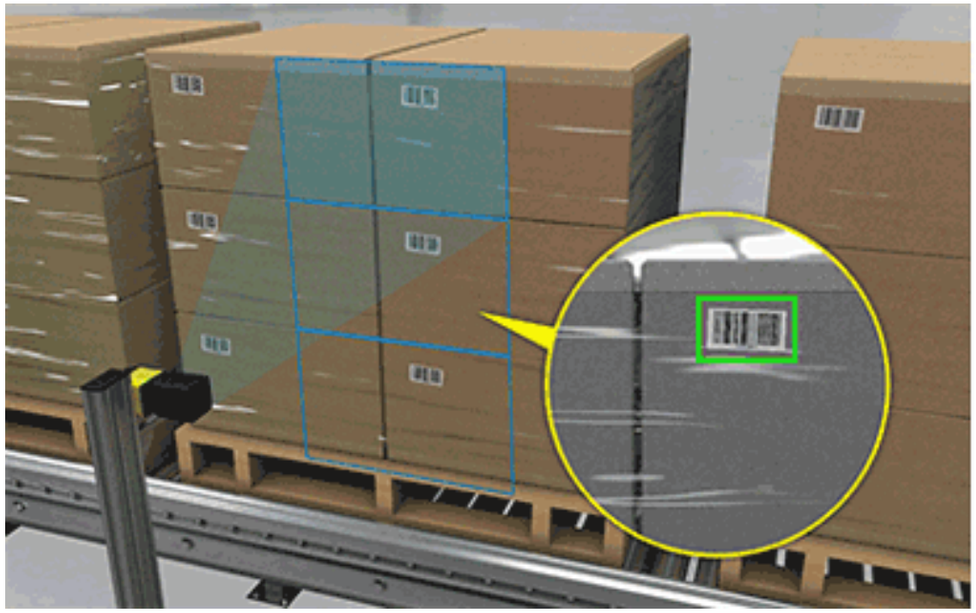
- Sensor: 1/1.8"
- Tunable lens: EL-16-40-TC-VIS-5D
- Imaging lens: 50mm or 75mm
- FOV: 67° x 84°

Advantages

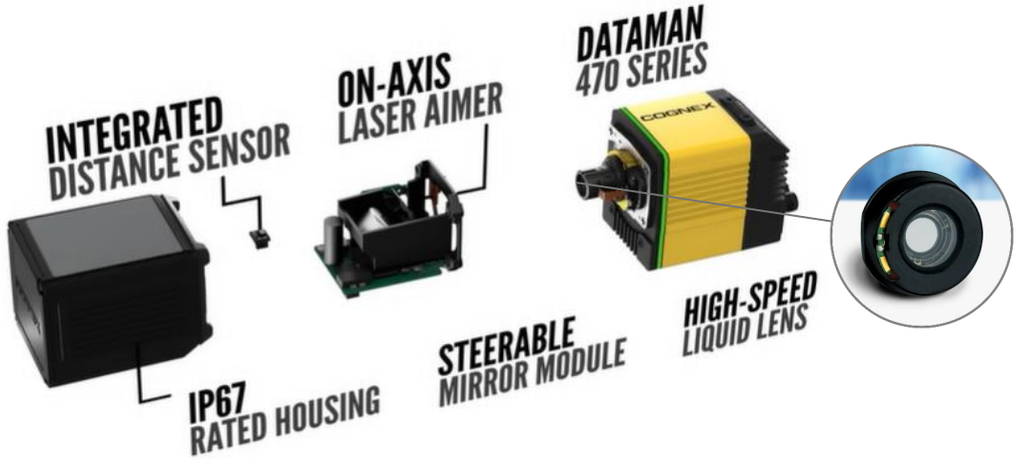
- Foviated vision system (imitating human eye)
- Ability to detect road-signs in 100m distance (0.3° FOV) with regular sensor size

optotune

Fast code reading across large field of view



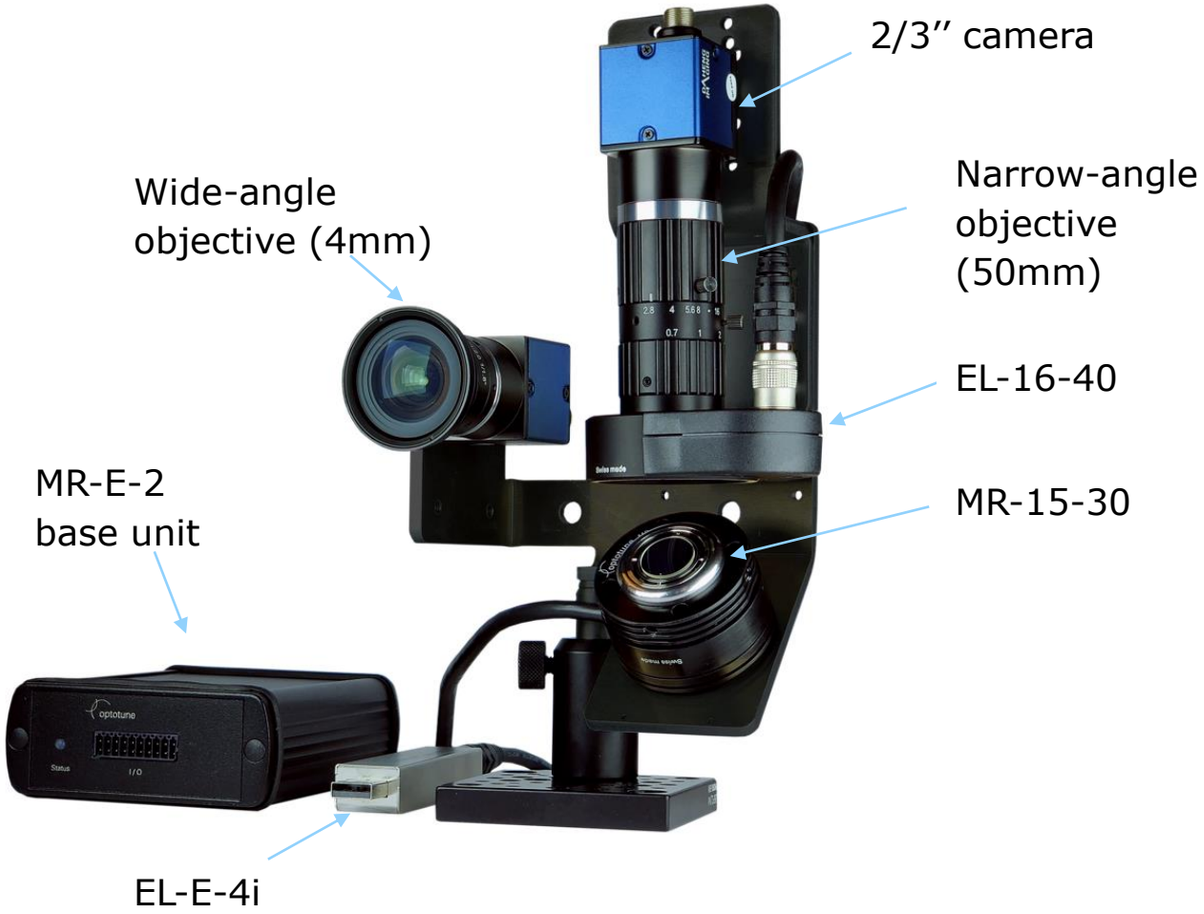
10X larger field of view



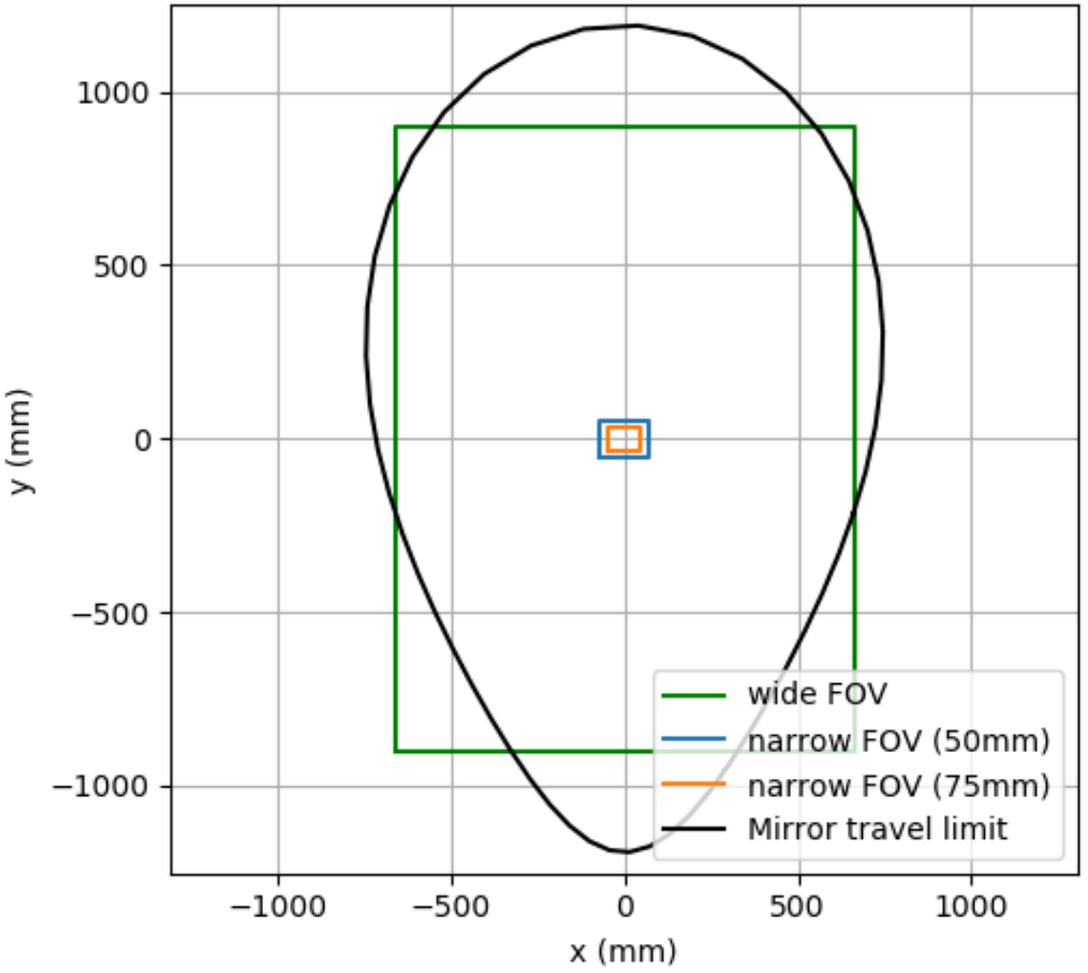
Focus from 10cm to infinity

optotune

FOV expansion allows to take 1.5GP images



Size comparison between the different field of views, at a 1m distant plane. The narrow angle FOV can be steered around within the mirror travel limits.



optotune

A «one gigapixel» view of Zurich

Try out and visit https://www.optotune.com/gigapixel-image

optotune

Agenda

- Introduction
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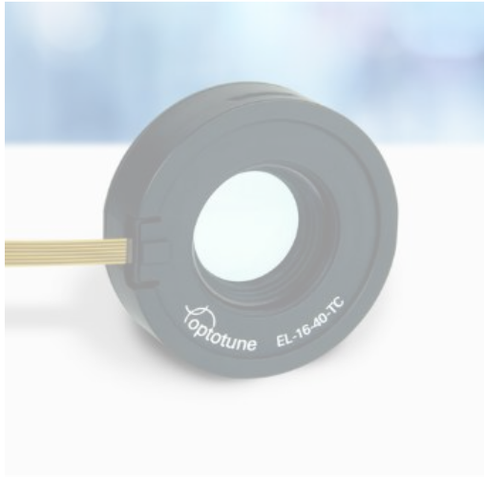
  - Applications
- Fast Steering Devices
  - Applications
- Beam Shifting Devices
  - Applications

Product Portfolio

Our solutions for Machine Vision

Focus tunable lenses

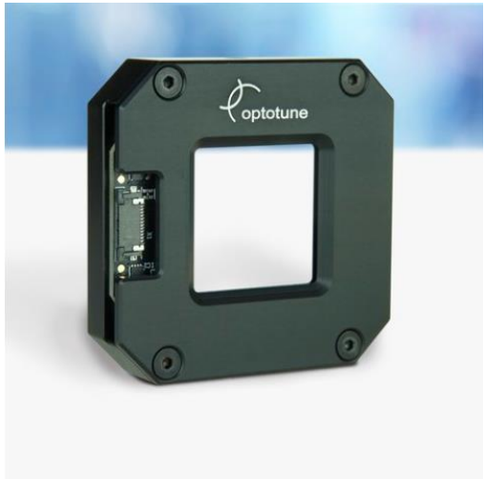


- Fast autofocus
- Fast detection
- Image stacking

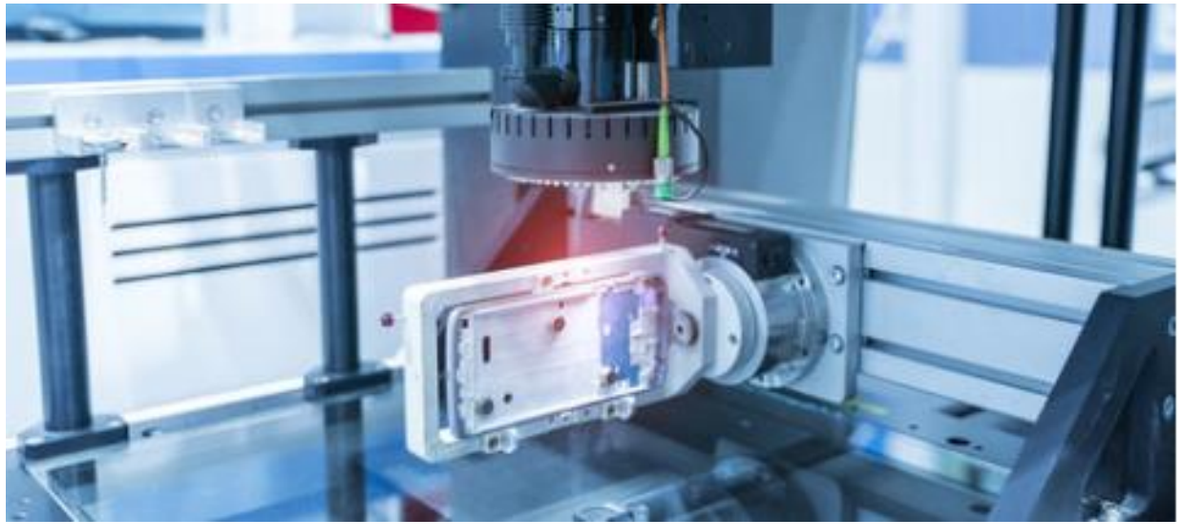
Beam steering devices

- Sole reflection
- Wide angular range
- Compact

Beam shifting devices



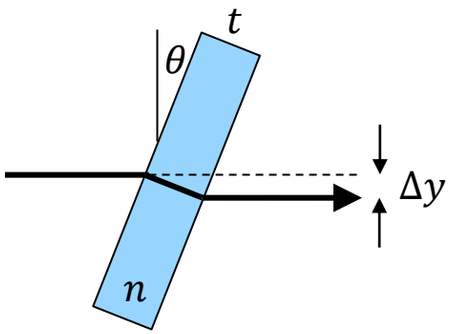
- Fast transition time
- Reliable over time
- Beam shifts up to 4.8um



optotune

How pixel shifting increases resolution

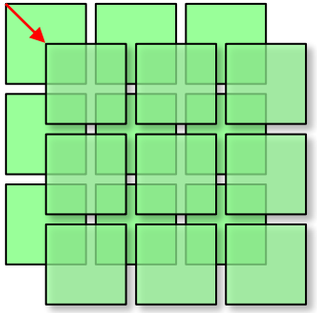
Tilting a window leads to lateral shift



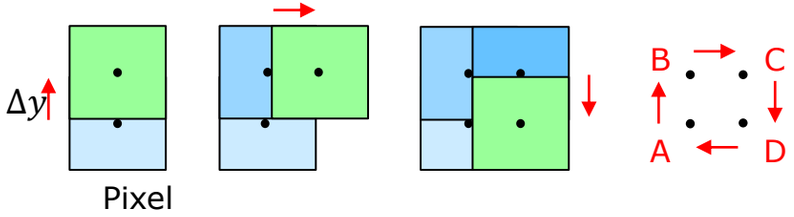
$$\Delta y = t\ sin\theta \left(1 - \sqrt{\frac{1 - sin^2\theta}{n^2 - sin^2\theta}}\right)$$

Example: A 0.7mm thick BK7 window tilted by 1° achieves a shift of 4um

A diagonal 2-position shift doubles resolution

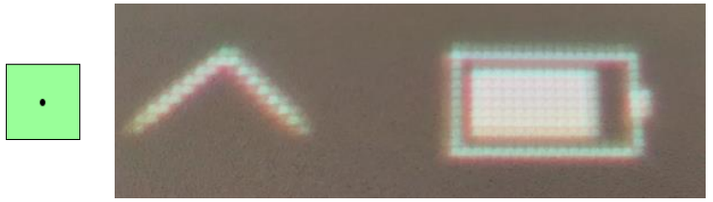


A 4-position shift in X&Y quadruples resolution

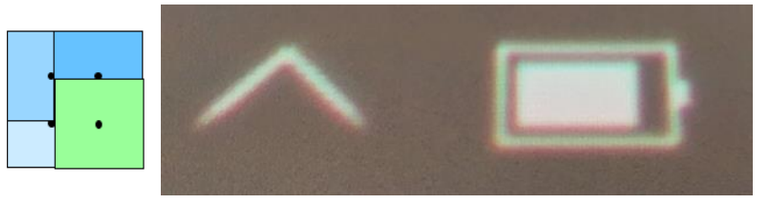


DLP projector example: Resolution increase from 1080p to 4K

Pixel shifter OFF:



Pixel shifter ON:



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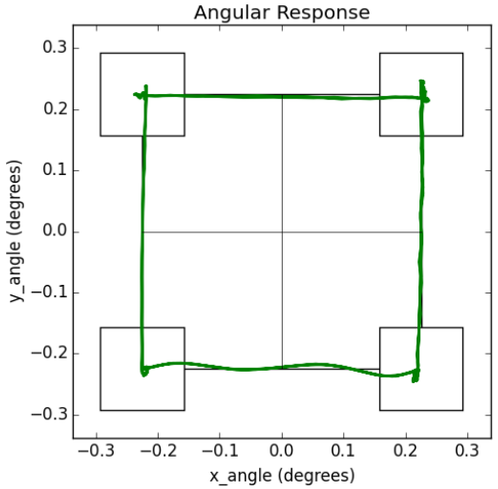
Beam shifting windows for resolution enhancement

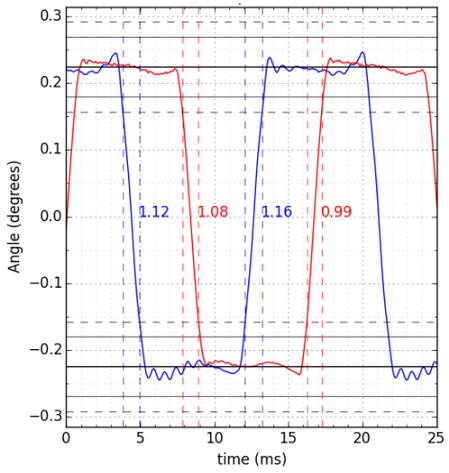
Specifications

- Clear apertures from 9 to over 40 mm
- Tilt angle up to 0.9°, beam shifts up to 5.4 µm
- Transition times down to 1ms
- Beam shift accuracy of 10%, pre-calibrated
- Acoustic noise below 20 dBA at 30cm
- Lifetime beyond 20’000 hours

Benefits

- Several DLP and image sensor sizes supported
- Pixel sizes of up to 10.8 µm supported
- Little light loss during switching
- Consistently high optical performance
- Silent operation
- Suitable for 24/7 operation





optotune

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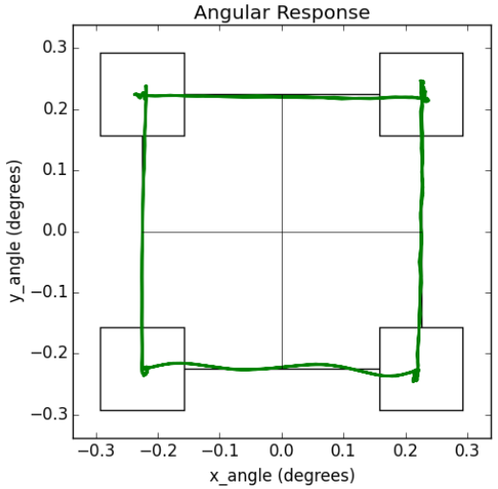

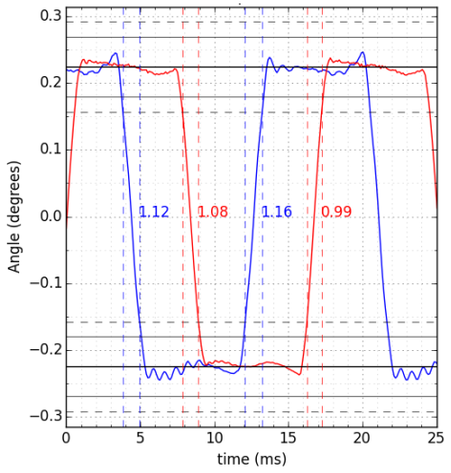

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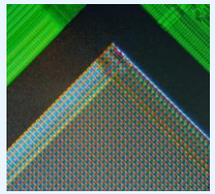
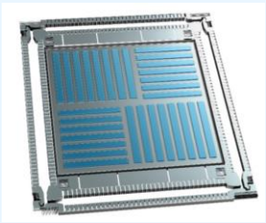
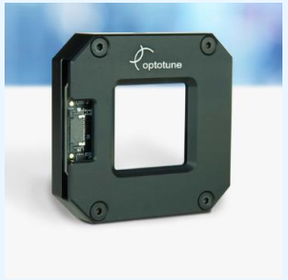
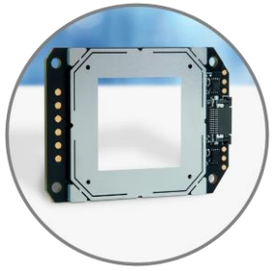
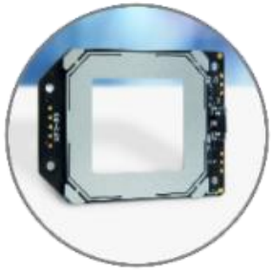
Current solutions

To increase camera resolution

	Smaller pixels	Larger Sensor, bigger optics	Sensor shift	Image shift	
					
Frame rate	+	+	-	-	
Light sensitivity (signal to noise)	-	+	+	+	Larger pixels can be used
Flexibility	-	-	+	++	Can be integrated into objective, or miniaturized into camera
Price	$	$$	$	$	
Price of compatible optics	$	$$	$	$	

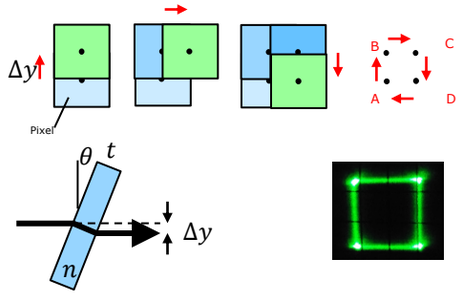
XPR overview

	XPR-9-2P	XPR-20-4P	XPR-33-4P	XPR-4X-4P
				
Clear aperture size	9x5 mm	20x20 mm	33x31 mm	Custom designs up to 55 mm
Window tilt angle (standard operation)	0.9°	0.2°	0.3°	0.3°
Beam shift in transmission	3.8 µm (diagonal)	2.7 µm in X & Y	3.8 µm in X & Y	5.4 µm in X & Y
Transition time	1.0 ms	1.2 ms	1.4 ms	1.1ms
Applications	Pico projectors, HMDs	4K Laser TV, 3D printers	High-lumen 4K projectors	Digital cinema, 3D printers

Agenda

- Introduction
- Liquid Lenses
  - Solutions for fast focusing
  - Optics configuration tools
  - Applications
- Fast Steering Devices
  - Applications
- Beam Shifting Devices
  - Applications

High resolution imaging (monochrome camera)



Beam shifting OFF

Beam shifting ON

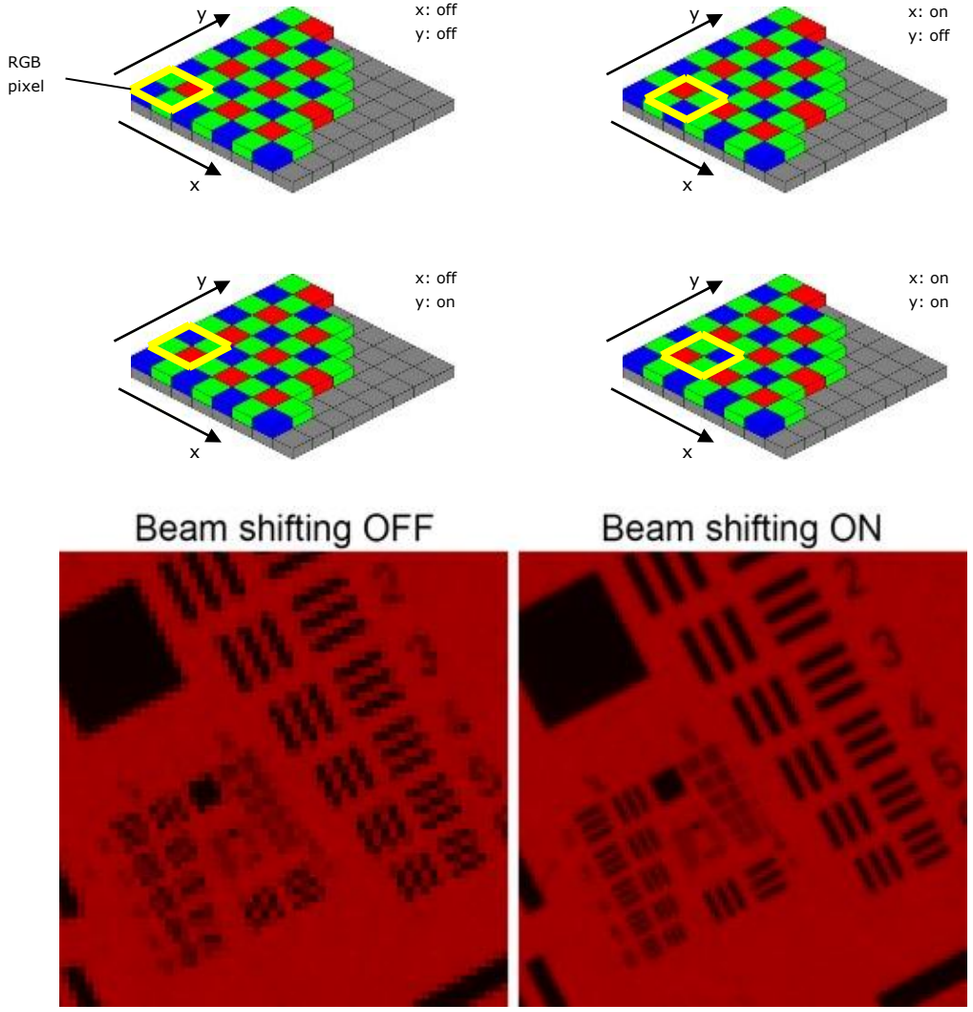
Setup

- Sensor: 1" CMOS, Sony IMX183
- Pixel size: 2.4 µm
- Lens focal length: 35 mm
- Beam shifter: BSW-20
- Native resolution: 198 lp/mm
- Beam shift enabled resolution: 280 lp/mm

Advantages

- Increase in lateral resolution: +40%
- High signal to noise thanks to larger pixels
- Increase resolution where smaller pixels or larger sensors are not available or too expensive

High resolution imaging (color camera)



Setup

- Sensor: 1/1.8" CMOS, Sony IMX265
- Pixel size: 3.45 µm
- Lens focal length: 35 mm
- Beam shifter: BSW-20
- Native resolution: 65 lp/mm
- Beam shift enabled resolution: 130 lp/mm

Advantages

- Increase in lateral resolution: +100%
- Avoid interpolation in color cameras. Achieve full resolution in all color channels.

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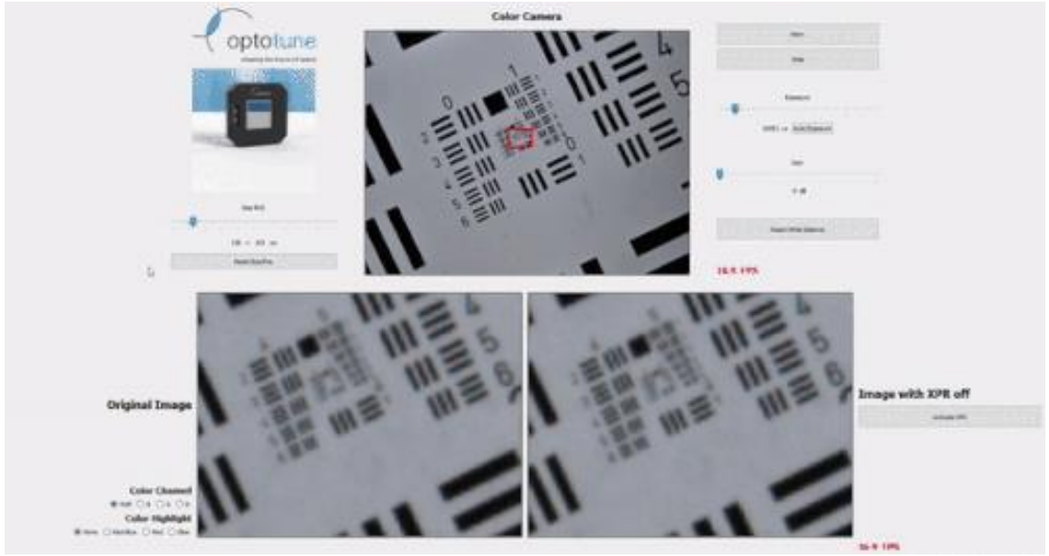
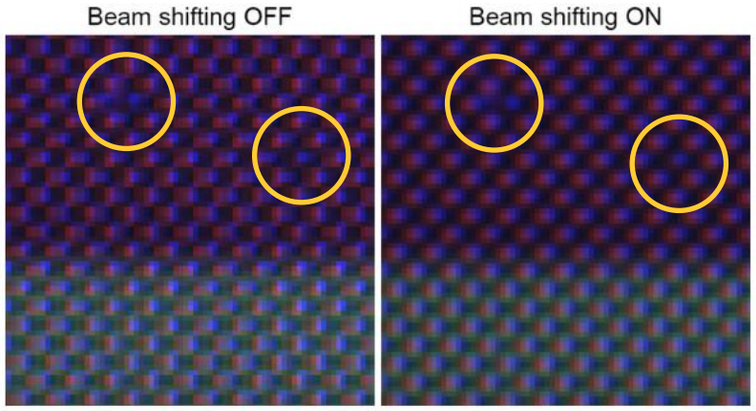
Display inspection





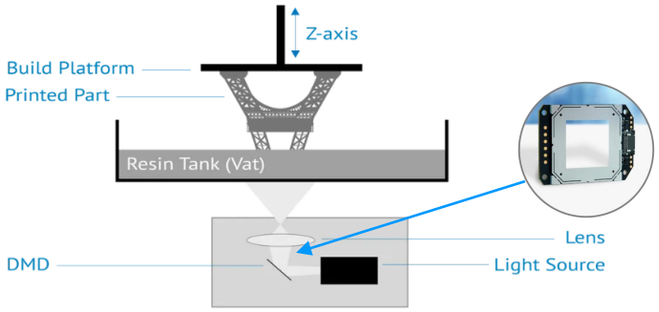
Setup

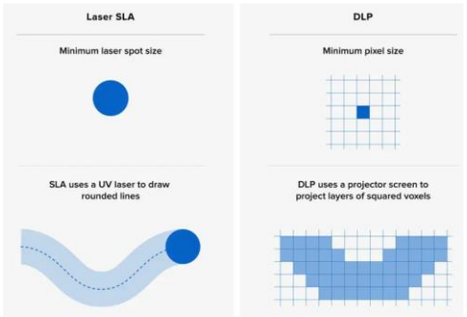
- Sensor: 1/1.8" Sony IMX265 CMOS
- Lens focal length: 35 mm
- Beam shifter: BSW-20

Advantages

- Increase in lateral resolution: +100%
- Avoid interpolation in color cameras.
  -> avoid false color information
- Easier detection of pixel defects
- Image large FOV at required resolution

3D printing





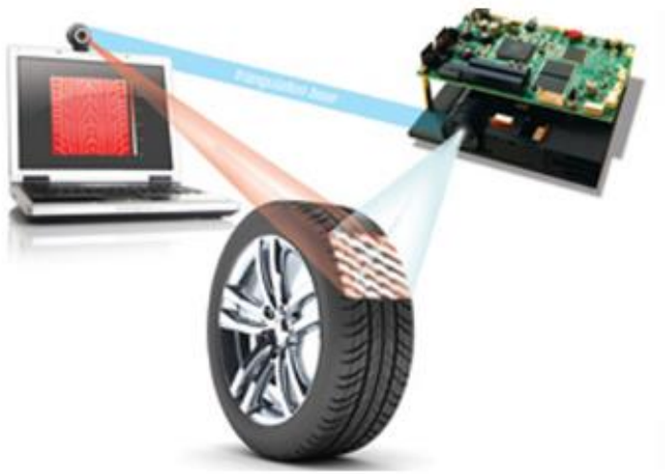
Setup

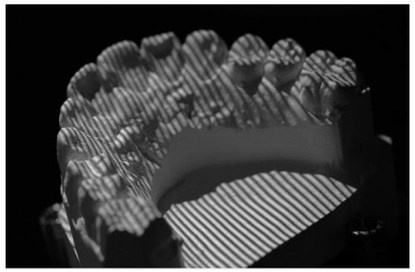
- DLP based 3D printer
- Beam shifter: BSW-20

Advantages

- Pair fast printing speed with high resolution
- Beam shifter can be activated on demand, for best trade-off between resolution and speed
- Proven technology in consumer to high-end projectors

3D scanning with structured light





Setup

- DLP based structured light projector

Advantages

- High resolution inspection or 3D scanning
- Compact
- Proven technology in consumer to high-end projectors

ONE MILLION LENSES IN ONE

OPTOTUNE EL-16-40 LIQUID LENS

THE SWISS SHAPE SHIFTER - FROM CONCAVE TO CONVEX IN JUST A FEW MILLISECONDS