optotune

Focus tunable liquid lenses

And how to integrate them in machine vision systems

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Agenda

- Introduction
- How to combine ELs with off-the-shelf optics
  - Entocentric lenses
  - Telecentric lenses
  - Microscopy
- Custom designs
- Optics configuration tools
- Standard liquid lenses, drivers & software
- Application examples

Optotune on a page

optotune
shaping the future of optics

Established in 2008

Leader in tunable optics

28 sales partners in 30 countries

185 employees
- **118 in Switzerland**
- **60 in Slovakia**
- **7 in sales offices**

Privately owned

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 >

Certified System SWISS TS ISO 9001

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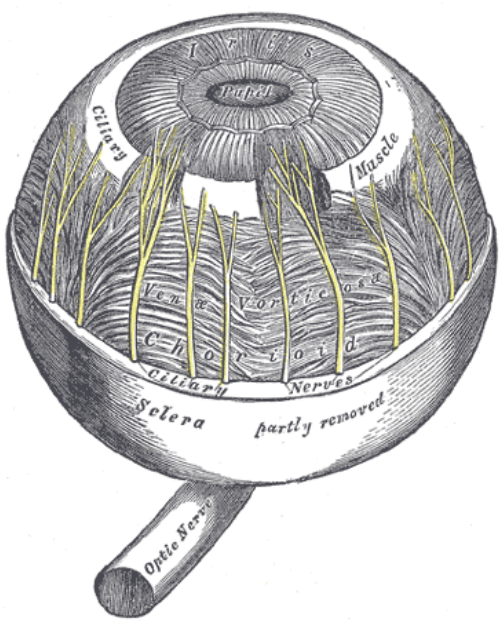
Working principle: membrane with fluid and actuator

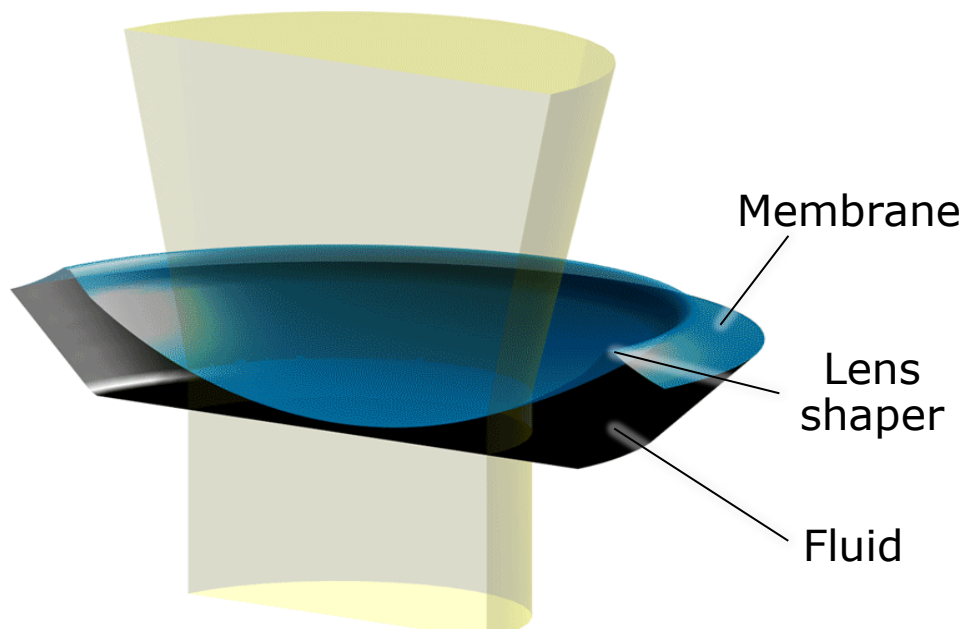
Human eye:

Ciliary muscle actuates the lens curvature



Optotune lens:

Electromagnetic actuator controls the lens curvature



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

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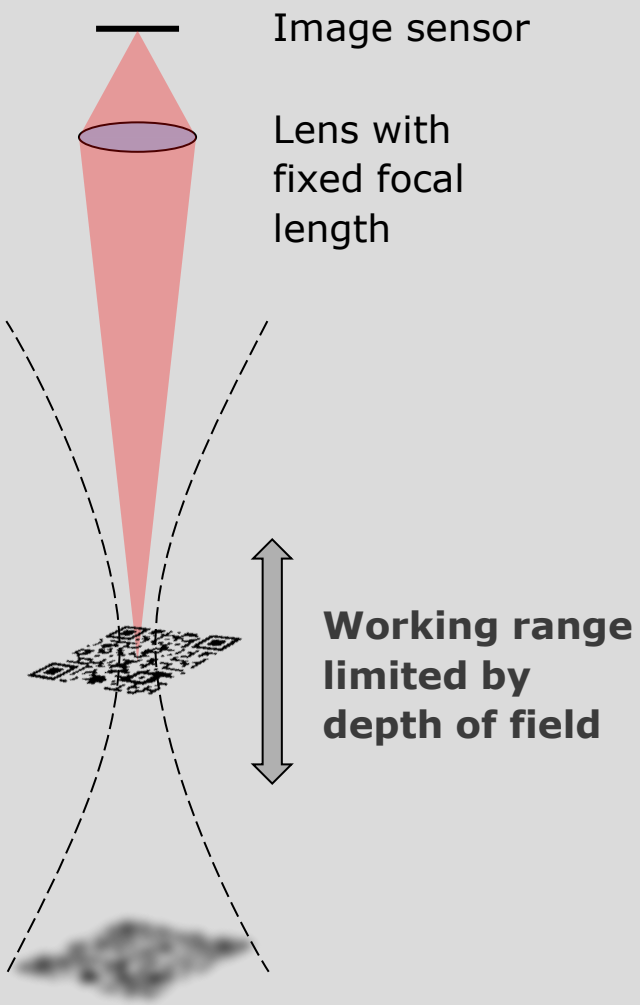
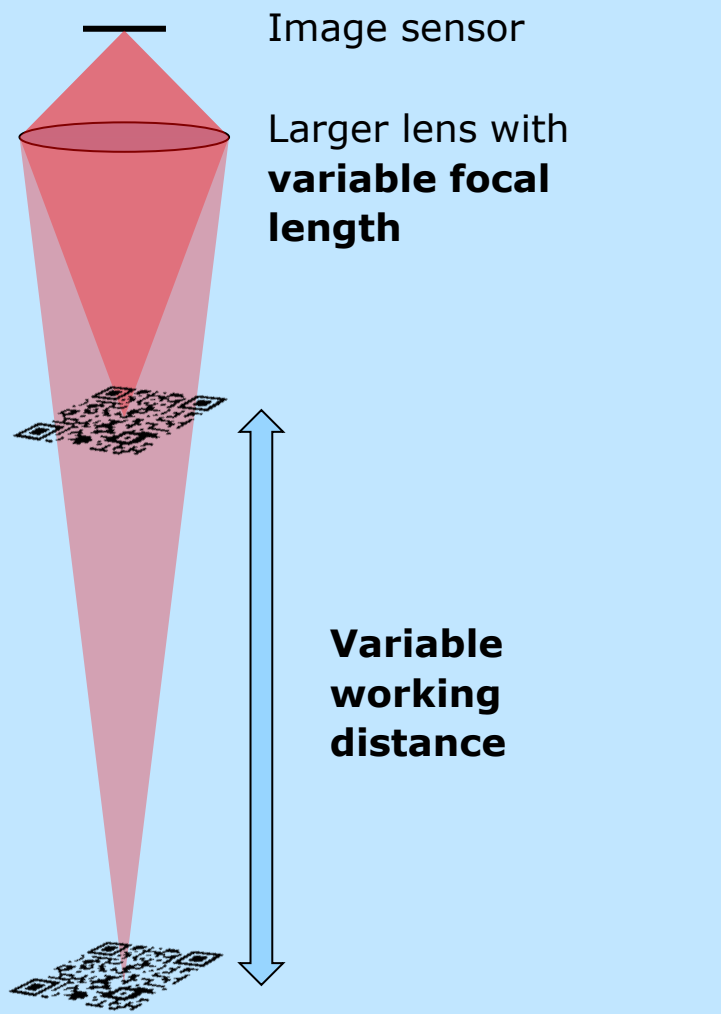
The ideal focusing solution for machine vision

Fixed focus optics



Liquid lens approach



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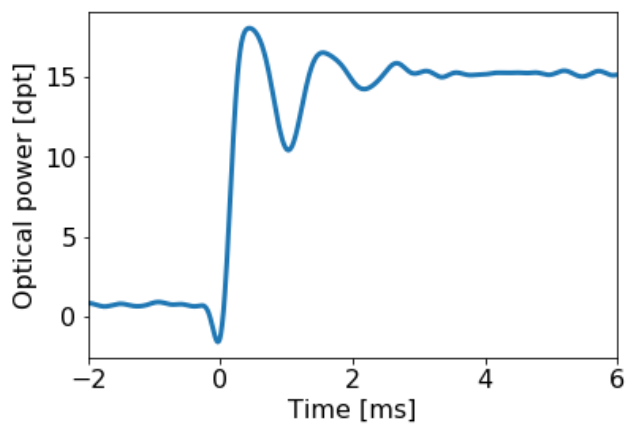
The natural way to focus: Like your eyes but faster!

Specification	Your benefit
Apertures from 3 to 30mm	Sensor sizes from 1/3” to 40mm supported
Large working distance range	No need to increase F# for larger depth of field
Low dispersion (Abbe# V>100)	No color aberrations introduced
>10^9 cycles	Long lifetime
High repeatability <0.1 dpt (automatic temperature compensation)	Once calibrated, the system runs open loop
Response times of few millisecods	Increase your throughput!

EL-3-10
Response: 1ms
Settling: 4ms



Demo videos

Demonstration at VISION Stuttgart 2018
https://youtu.be/PRQ5XjLPzfk

Webinar June 2019
https://event.webcasts.com/viewer/event.jsp?ei=1244817&tp_key=d494d69939&sti=optowww

Focus stacking in real-time
https://youtu.be/-NBXIMhBlUQ

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Four main configurations for machine vision applications

Conventional fixed focal length lenses	Telecentric lenses	Microscopes

Front-lens config.

C- or S-mount lens

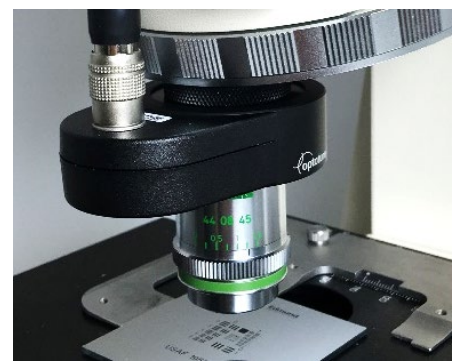
Working distances typically long (from 100mm to infinity)

Back-lens config.

Fixed focal length lens >=35mm

Working distances typically short (from 50mm to 500mm)

Magnifications: from 0.13X to 4X



Up to 100x magnification

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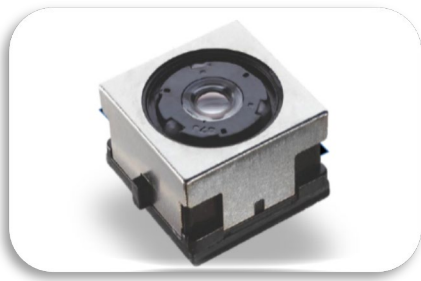
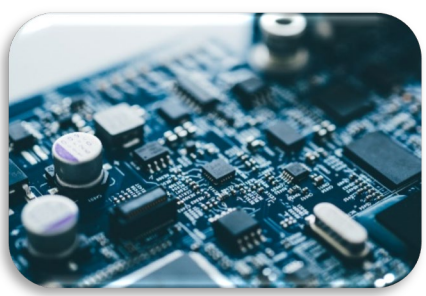
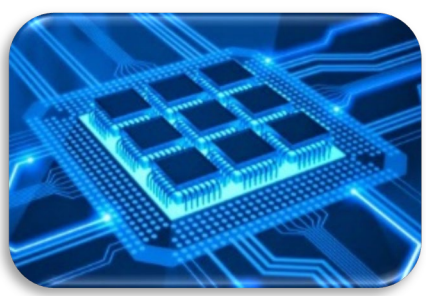
Four main configurations for machine vision applications

Conventional fixed focal length lenses		Telecentric lenses	Microscopes
Front-lens config. Large WD	**Back-lens config. Short WD**	**Constant magnification**	**High magnification**
Package sorting	Contact lens inspection	Camera phone lens inspection	Particle counting in liquids
			
Robot vision	Electronics inspection	IC inspection	Microscopy
			

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Front-lens configuration typically for large working distances

Front-lens configuration

C-mount camera

12mm board lens

C- to S-Mount adapter

EL-10-30

3 cm

6.5 cm

Fixed focal length lens

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

Working distance ranges from infinity to about 100mm

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Large FOV for small sensors with 7.2mm S-mount lens & EL-16-40-TC

Front-lens configuration

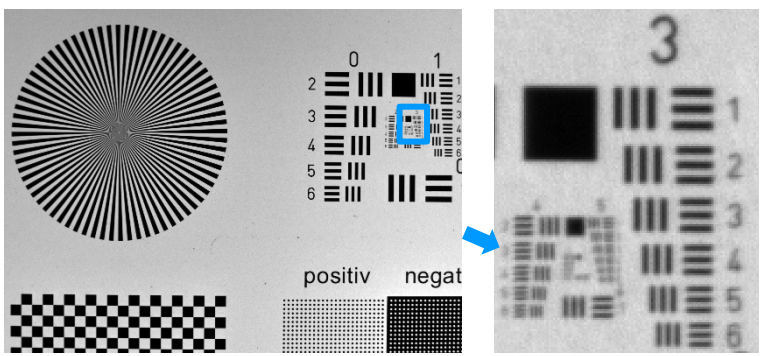
C-mount camera with up to 1/2.3” format sensor

Inside:

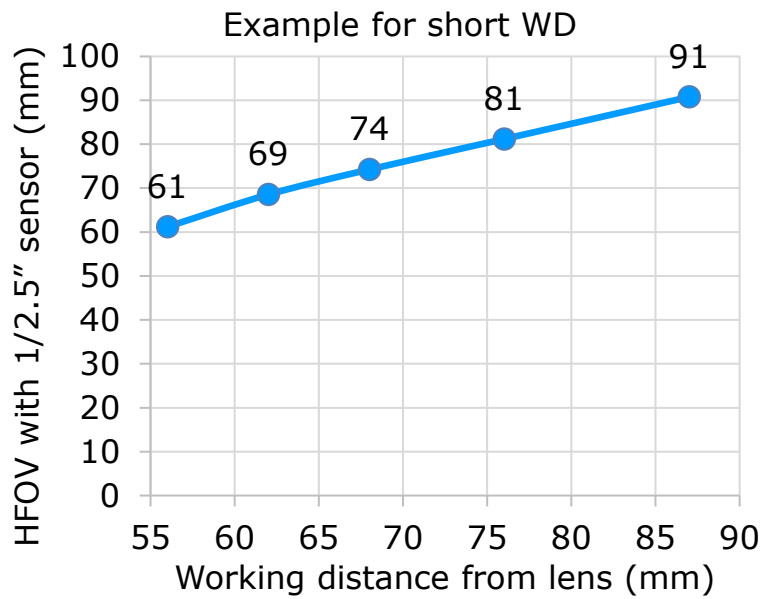
- S- to C-mount adapter AD04M
- Lensation B10M7224 7.2mm S-mount lens

15mm C-mount spacers

EL-16-40-TC-VIS-5D-C



~160 lp/mm
→ Suitable for 2um pixel size!



53° HFOV with 1/2.5” sensor

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

Back-lens configuration

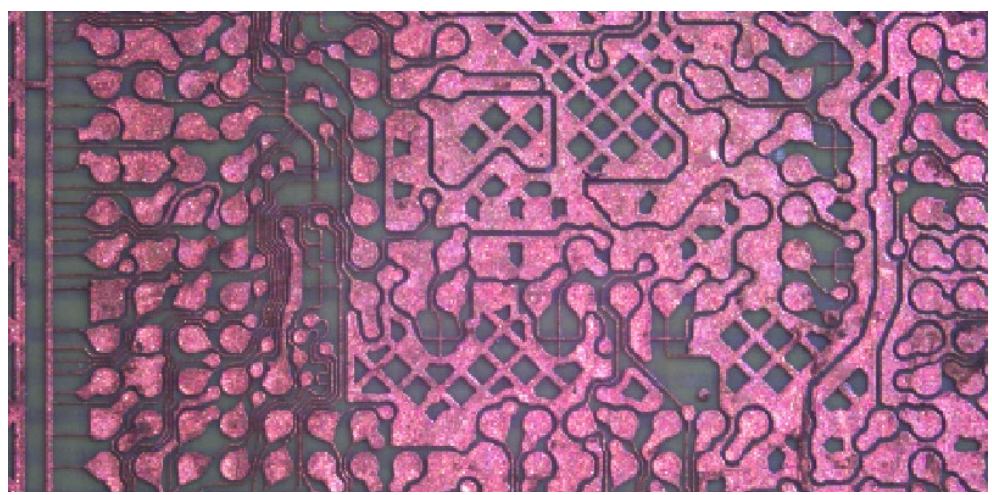
C-mount camera

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

50mm lens
e.g. Tamron 23FM50SP

Results	EL-10-30	EL-16-40	Unit
50mm lens focus	∞	∞	mm
Magnification	0.4x	0.4x	
WD @0dpt	160	200*	mm
Z range	25	40*	mm
HFOV @0dpt on 1/2” sensor	18	20	mm

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



This only works for lenses with focal length >= 35mm

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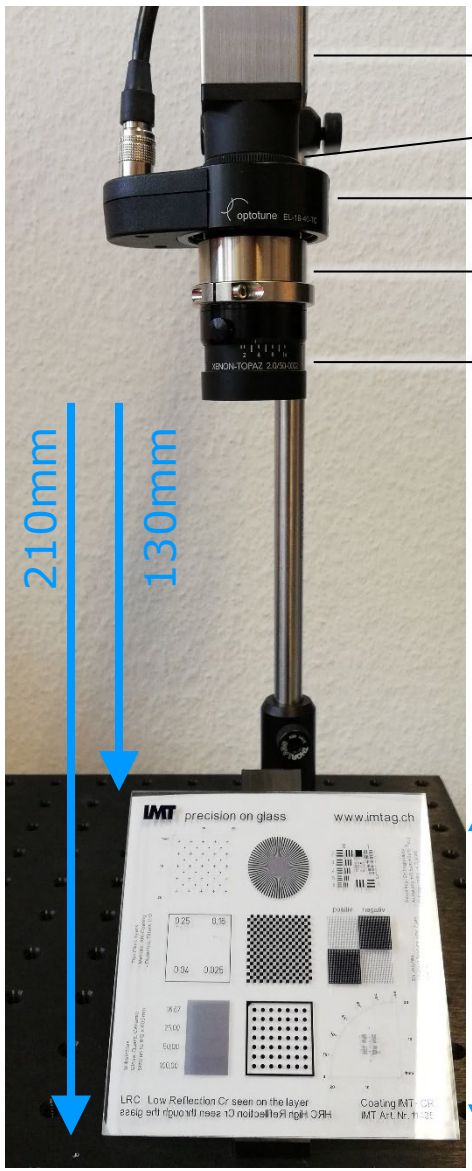
Optimized back lens configuration with Xenon Topaz 50mm lens

Back-lens configuration



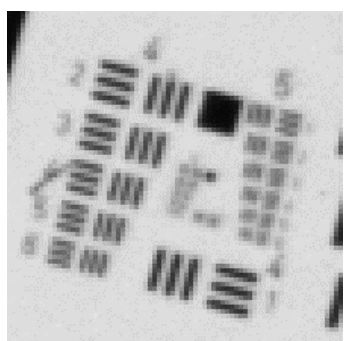
C-mount camera with 1” sensor

5mm C-mount spacer

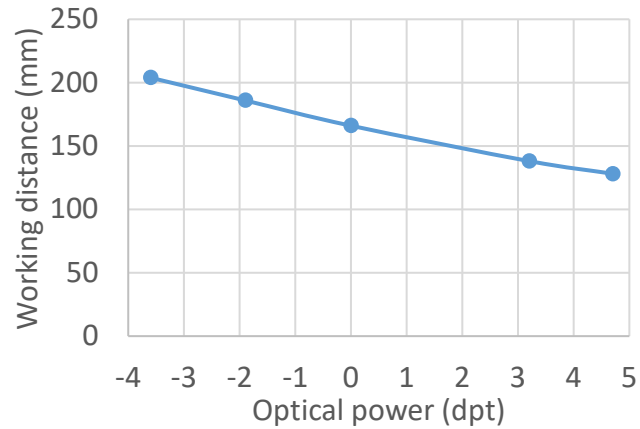
Optotune EL-16-40-TC-VIS-5D-C

C-mount adapter from Xenon Topaz 38mm*

Schneider Kreuznach Xenon Topaz 50mm



WD range: ~70mm



Optical power	WD from lens	HFOV on 1” sensor	PMAG	Resolution on Object
-3.6 dpt	204mm	44mm	0.28X	17um
-2 dpt	186mm	42mm	0.30X	16um
0 dpt	166mm	40mm	0.31X	15um
3 dpt	138mm	36mm	0.34X	14um
4.7 dpt	128mm	35mm	0.35X	14um

Optical leverage: 7-10mm/dpt

*The C-mount adapter of the Xenon Topaz 38mm lens is about 5mm shorter than the adapter of the 50mm lens. Hence the back flange distance of the 50mm lens is reduced, bringing it closer to the tunable lens and camera, which results in higher optical leverage of this configuration that with standard 50mm C-mount lenses

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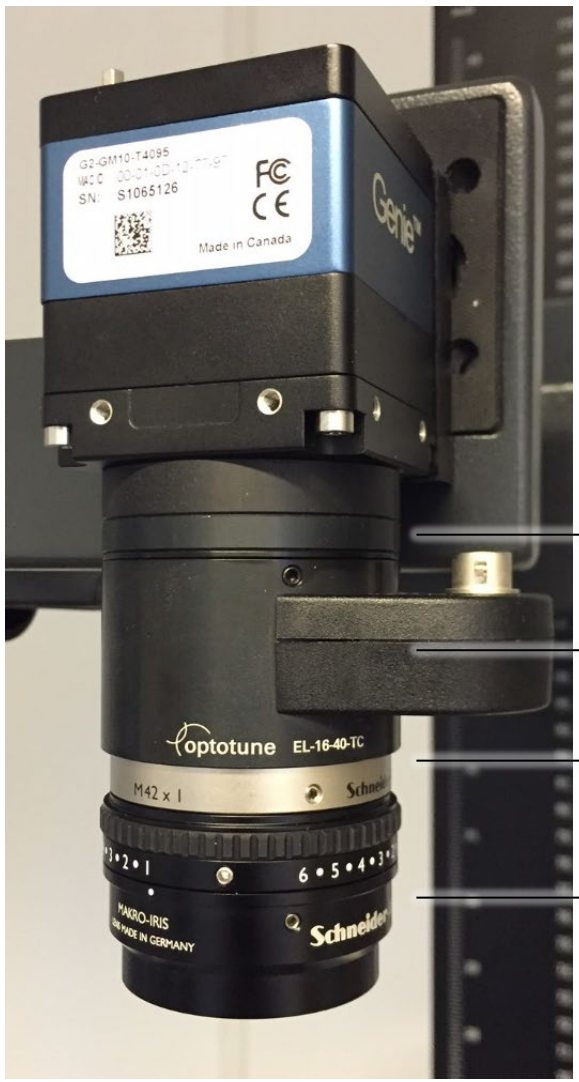
Image circles of 30mm possible

Back-lens configuration



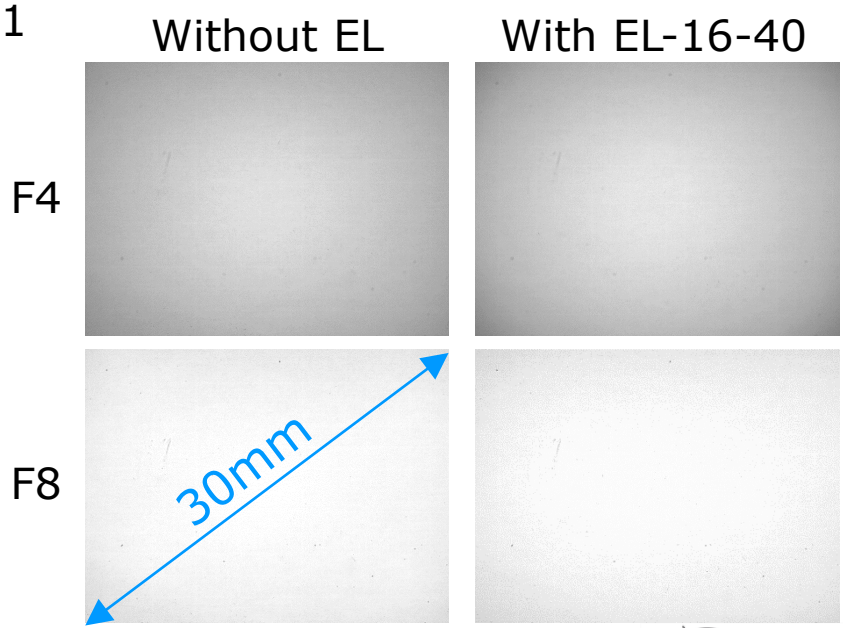
- WD range: from 1100mm to 380mm @ -2Dpt to 3Dpt
- Distortion unchanged
- Resolution equally good
- No added vignetting

13mm of spacers M42x0.1

EL-16-40-TC-VIS-M42

8mm spacer

Apo-Componon 60mm lens



Test report available online: http://www.optotune.com/applications/machine-vision

Note: Infinite focus is possible by using only 8mm instead of 13mm of spacers at the back.

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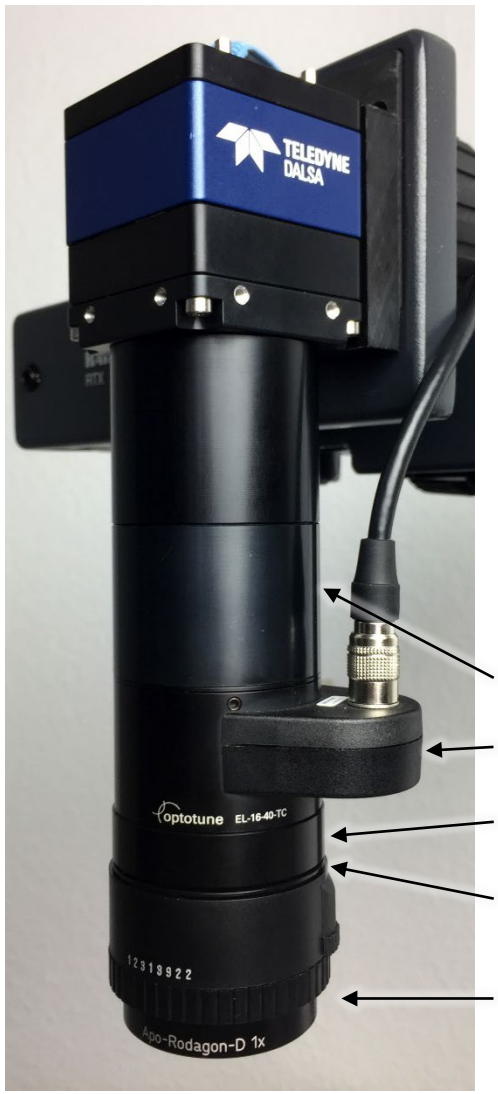
Low distortion 1x solution for large sensors

Back-lens configuration



95mm of M42 spacers

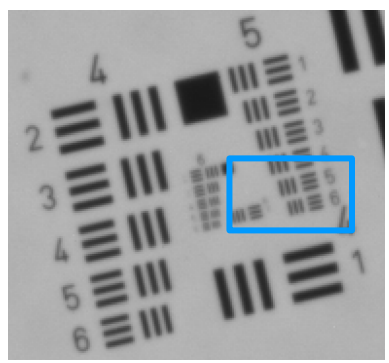
EL-16-40-TC-VIS-5D-M42

11m long M42 spacer

M39 to M42 adapter

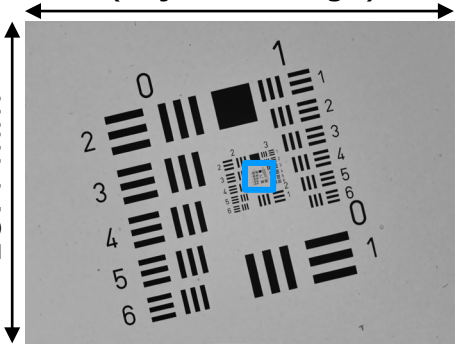
Apo Rodagon D1x 75mm F/4 lens*

- Large z-range of 57mm achieved with +/-2 dpt
  - Optical leverage is ~14mm per diopter
- Magnification changes slightly with 0.5% per mm of WD change
- Slight vignetting at F4, no vignetting at F5.6 or higher
- No distortion measurable at 0 dpt and 1 dpt
- Nominal resolution of ~64lp/mm is maintained after adding EL-16-40 when optical axis is vertical
- In Horizontal optical axis a resolution of ~57lp/mm can be achieved by stopping the lens down to F11



24.5 mm (object & image)

18.4 mm



USAF element:	6/1
Line width (um):	7.81
Lp/mm (object):	64
Magnification:	1.00
Lp/mm (image):	**64**
Nyquist limit:	83
Pixel size (um):	6

Test report available online: http://www.optotune.com/applications/machine-vision

* by Linos (formerly Rodenstock)

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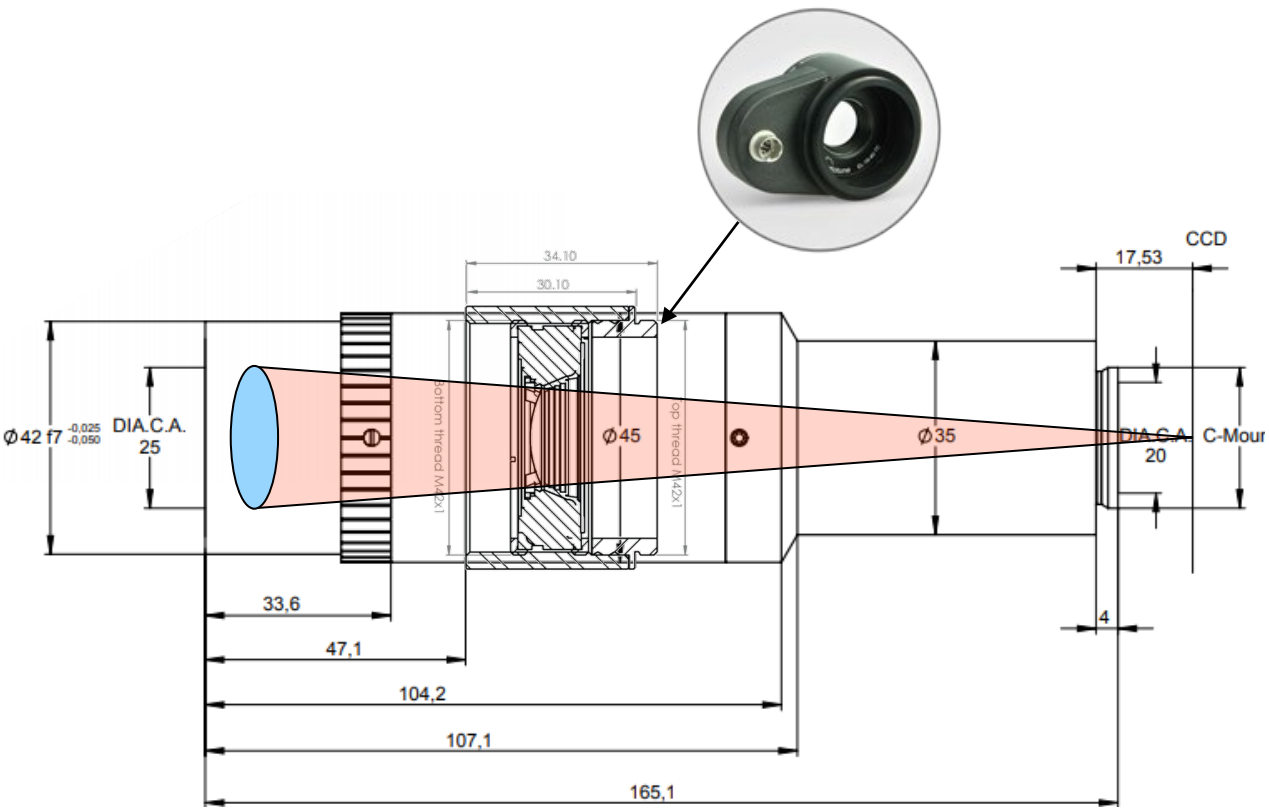
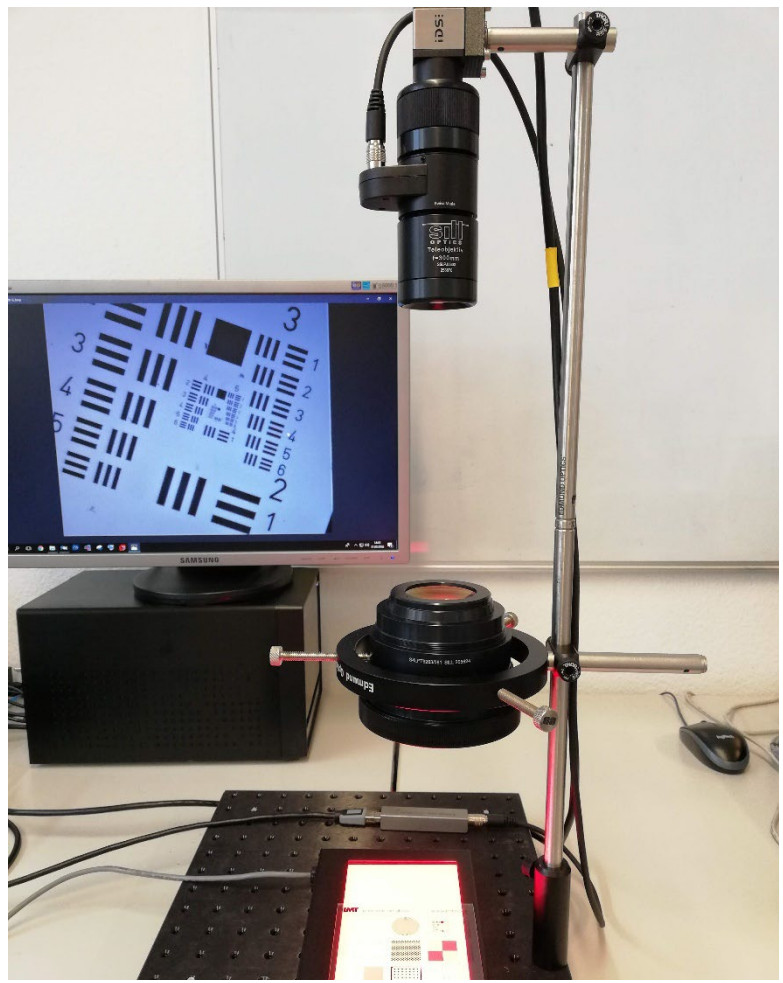
Focal lengths of 150mm or 300mm with EL-16-40 are ideal for imaging via galvos in laser pocessing

Example: EL-16-40-TC-VIS-5D-M42 integrated behind aperture of Sill Optics S5LPJ9034 150mm lens



Drawing: http://www.silloptics.de/fileadmin/user_upload/Downloads/Outline/S5LPJ9034.PDF

Example: EL-16-40-TC-VIS-5D-M42 integrated in Sill Optics S5LPJ0303 300mm lens



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Telecentric lenses preferably integrate the EL to achieve large Z-ranges

Moritex MML1-ST150D
with integrated EL-16-40

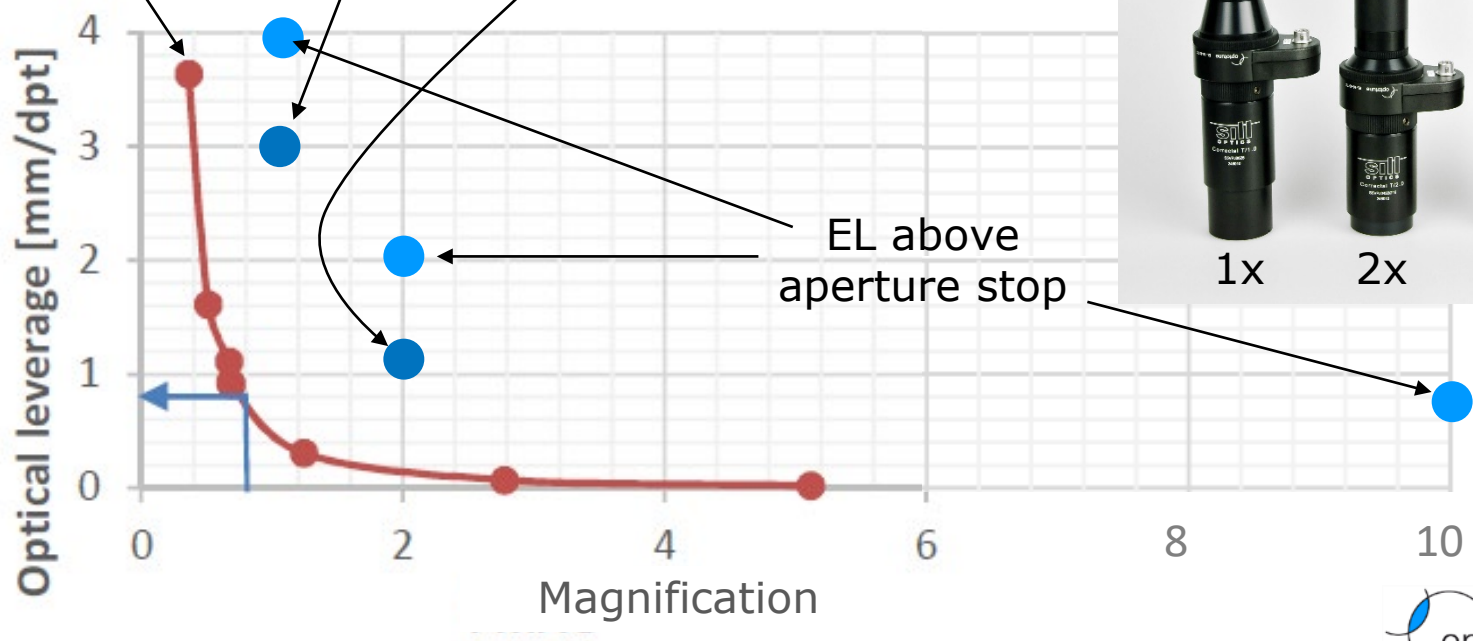
- 15mm Z-range
- <5% mag change

Moritex MML2-HR110
with integrated EL-16-40

- 5.5mm Z-range
- <8% mag change

Std back-lens configuration

$\mathbf{OL} \approx 0.5[mm/dpt] \ / \ PMAG^2$



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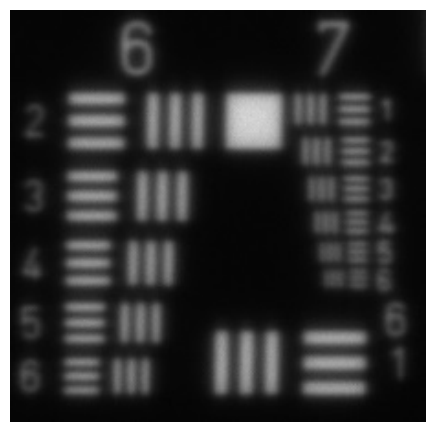
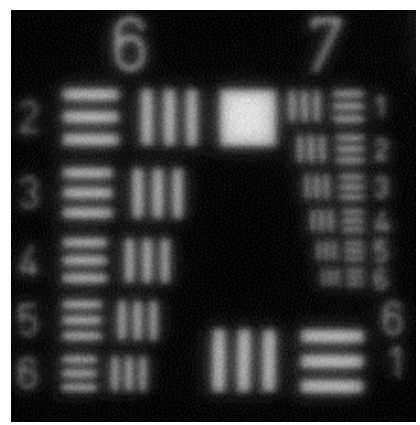
Optimized 2X telecentric lens for large formats

- 30mm image circle
- Large WD range: 105 +/-5mm
  - EL tuning from -2 to +3 dpt
- 4.5% mag change over full range
  - 0.45% per mm
- Resolution close to diffraction limit reaching 90lp/mm

Without EL



With EL-16-40



USAF group element:	7/4
Lp/mm (object):	181
Lp/mm (image):	90

Test report: http://www.optotune.com/images/products/Optotune%20EL-16-40-TC%20with%20Sill%20Correctal%20T_2.0%20telecentric%20lens.pdf

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Sill Optics offers variable focus telecentric lenses 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 supported by Coaxial illumination

Edmund Optics offers variable focus telecentric lenses from 0.15X to 0.75X

MercuryTL™ Liquid Lens Telecentric Lenses

- EL-10-30-Ci-VIS-LD-MV integrated behind aperture stop
- Demo video: https://youtu.be/36qwzmfCriM

Primary Magnification PMAG	Camera Sensor Format recommended & maximum	FOV @ 1/2" Sensor Format	Aperture (f/#)	Working Distance (mm)
0.15X	1/2"	41.2 x 30.9	f/10	169 – 265
0.24X	1/2"	26.5 x 19.9	f/10	91 – 173
0.37X	1/2" (2/3")	17.3 x 13.0	f/10	84 – 101
0.75X	1/2" (2/3")	8.7 x 6.5	f/10	85 – 99

Webshop: https://www.edmundoptics.com/imaging-lenses/telecentric-lenses/mercurytl-liquid-lens-telecentric-lenses/

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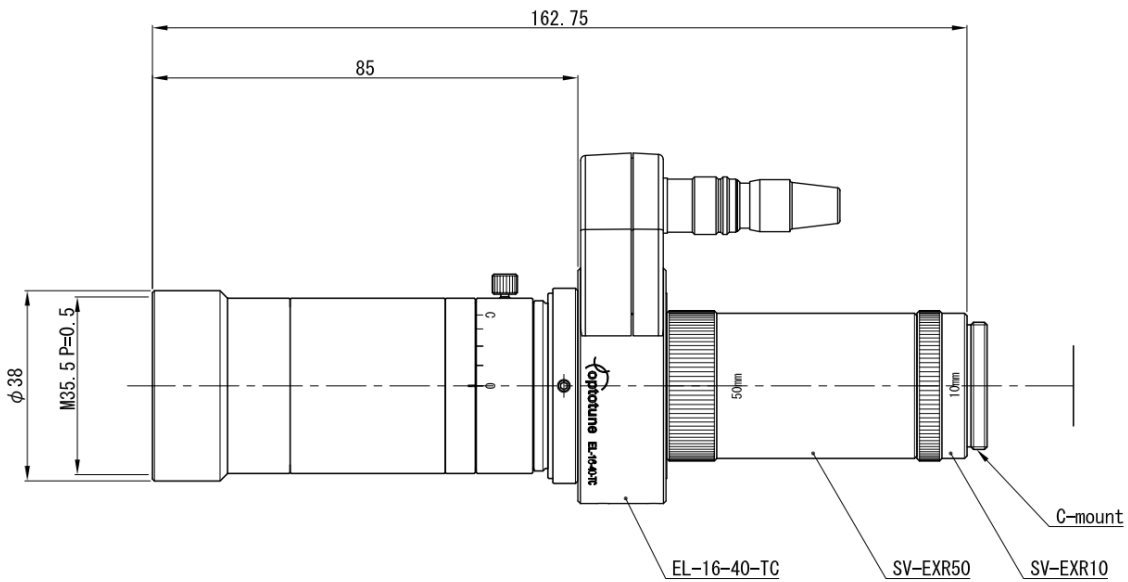
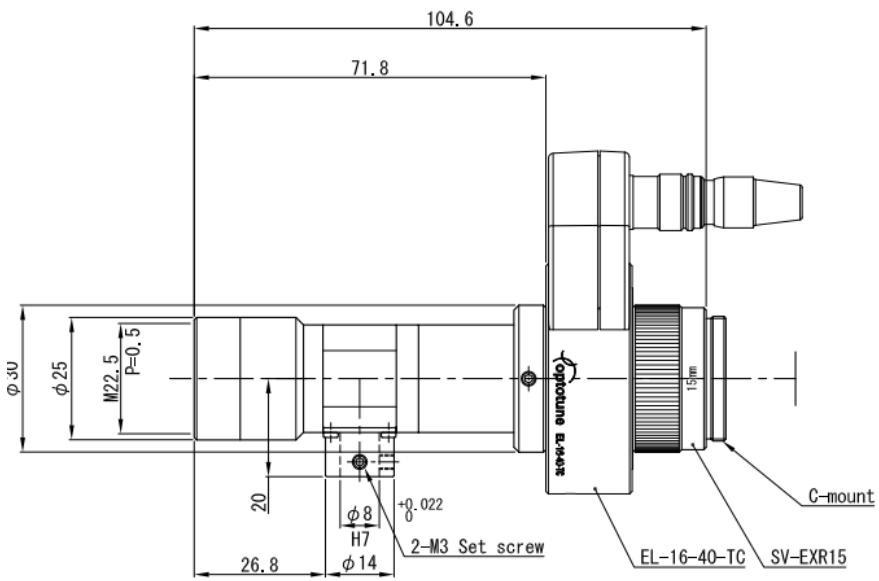
VST offers variable focus telecentric lenses from 1x to 4x

- EL-16-40-TC-VIS-5D-C integrated behind aperture stop

Primary Magnification PMAG	Model	Camera Sensor Format	FOV @ 2/3" Sensor Format	Aperture (f/#)	Resolution on object (um)*	Working Distance (mm)
1X (0.9–1.0)	VS-THV1-110_S-LQL1	1”	7.5 x 8.8	f/10	5.5	106.1 – 120.2
2X (1.8–2.0)	VS-THV2-110_S-LQL1	1”	3.8 x 4.4	f/9.6	TBD	105.4 – 115.6
2X (1.91–2.03)	VS-TCH2-65-LQL1	2/3”	3.8 x 4.4	f/13.5	TBD	63.5 – 66.1
4X (3.7–4.0)	VS-TCH4-65CO-LQL1	2/3”	1.9 x 2.2	f/17.5	TBD	64.7 – 65.3





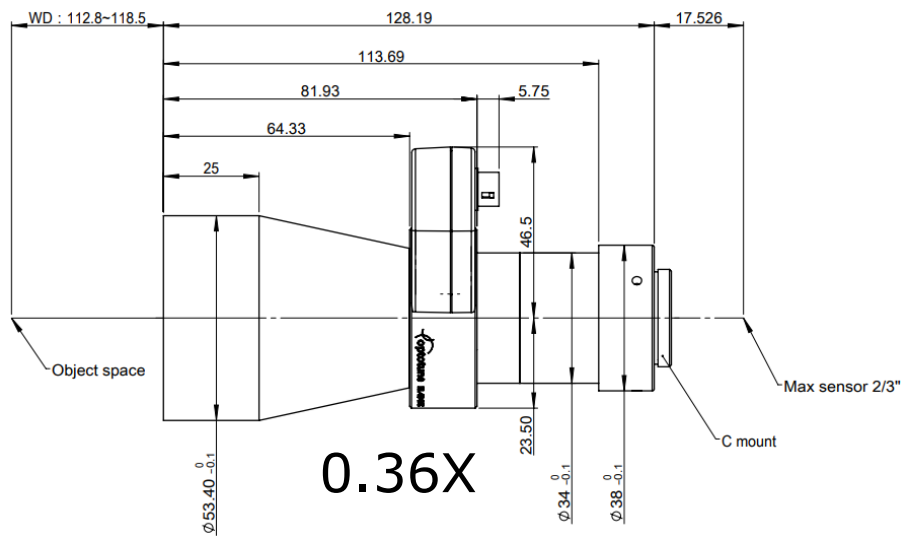
VST website: https://vst.co.jp/en/vs-lql1-series/
* Resolution is measured using **red**light with USAF target at a contrast of about 30% contrast

Linkhou offers variable focus bi-telecentric lenses from 0.36x to 2.0x

- EL-16-40-TC-VIS-5D-C integrated in front of aperture stop

Primary Magnification PMAG	Model	Camera Sensor Format	FOV @ max Sensor Format	Aperture (f/#)	Resolution on object (um)*	Working Distance (mm)
0.36X	TCPLP23-036-115	2/3”	23.5 x 19.6	f/4.5	8.7	115 +/- 15
0.6X	TCPLP23-06-115	2/3”	14.1 x 11.8	f/4.5	6.9	115 +/- 10
1.0X	TCPLP23-1.0-110	2/3”	8.5 x 7.1	f/10	5.9	106 – 116
2.0X	TCPLP23-2.0-110	2/3”	4.2 x 3.5	f/16	5.0	108 – 112

LINKHOU



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

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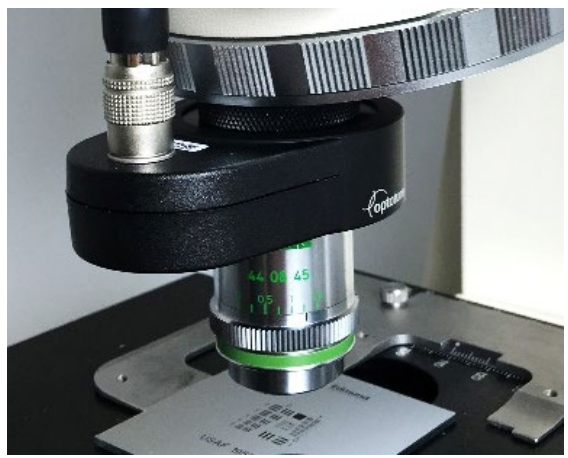
Agenda

- Introduction
- How to combine ELs with off-the-shelf optics
  - Entocentric lenses
  - Telecentric lenses
  - Microscopy
- Custom designs
- Optics configuration tools
- Standard liquid lenses, drivers & software
- Application examples

Integration of liquid lenses in microscopes

Non-telecentric

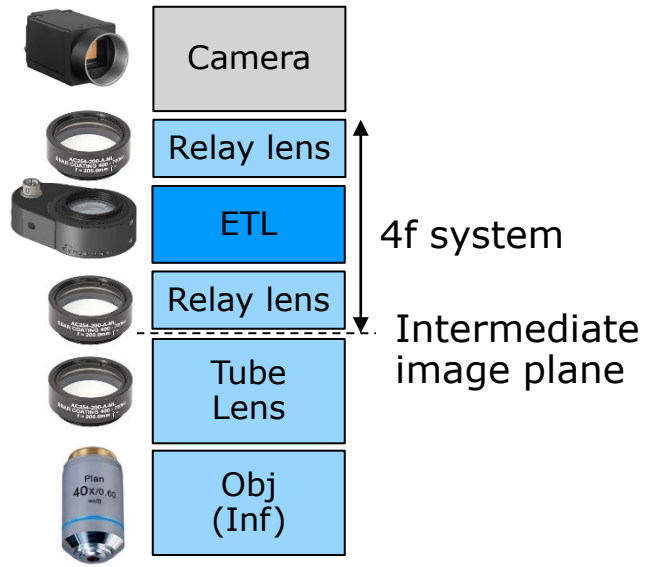
- Tunable lens right above objective lens (infinity corrected space)
- Largest Z-range, but with mag change



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

Telecentric

- Tunable lens at intermediary pupil position of a relay
- Smaller Z-range, but no mag change



	Z-range (typical)
10x	500 µm (20D: 2000 µm)
20x	125 µm (20D: 1000 µm)
40x	30 µm (20D: 120 µm)

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Microscope system for 10-100X incl. EL-16-40

- Non-telecentric setup for microscopy
- Sensor: Up to 1.1"
- Tube lens: 1x/0.8x/0.6x
- Tunable lens: EL-16-40-TC-VIS-5D-1-C*

  *Additional adapters required for tube lens and objective
- Objective lens: 10X to 100X

- Performance (with 1X Tube lens)

Objective lens			10X	20X	40X	100X
NA			0.25	0.50	0.65	0.95
Tuning Z-range*	[mm]		2.80	0.51	0.13	0.020
FOV	[mm]	1" Sensor	1.28 x 0.96	0.64 x 0.48	0.32 x 0.24	0.128 x 0.960
		1/2.3" Sensor	0.62 x 0.46	0.31 x 0.24	0.16 x 0.12	0.062 x 0.046

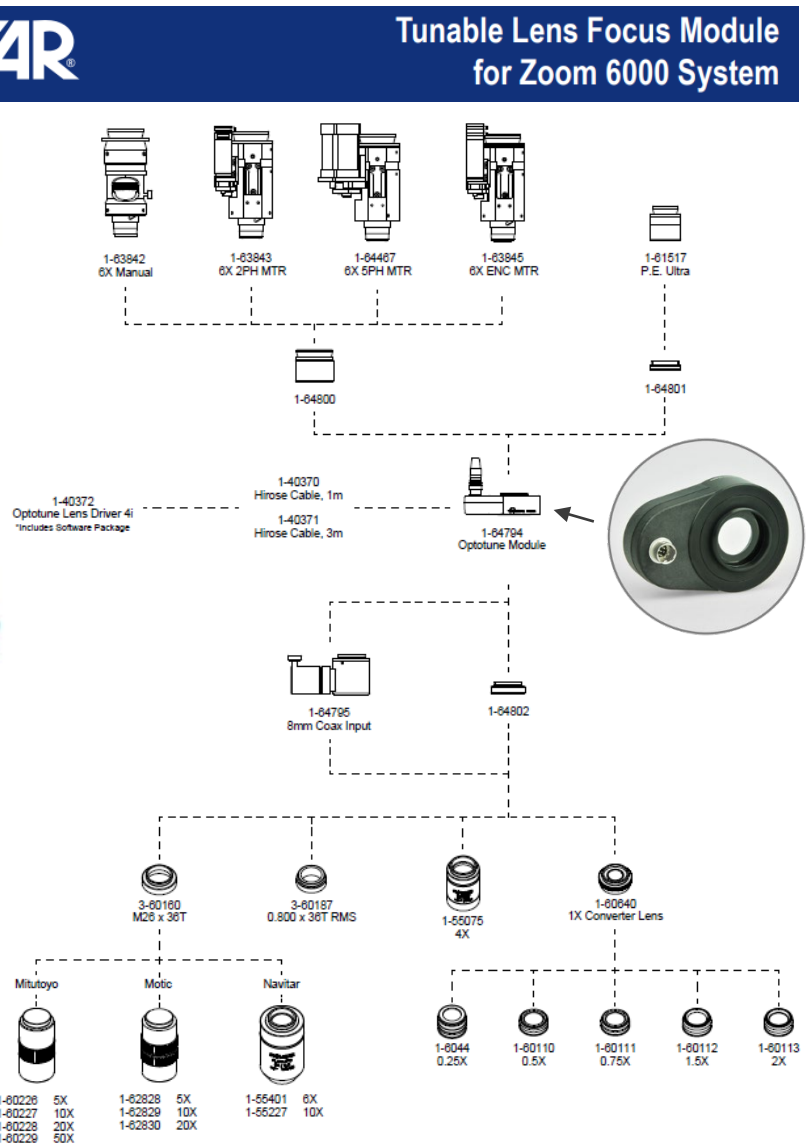
* Black : Measured Value; Blue : Estimated value.

Navitar industrial microscope with EL-16-40-TC autofocus module

- Modular system for zoom applications
  - Zoom is parfocal as the EL is placed below the zoom
- Also suitable for fixed mags
- Compatible with several microscope lenses up to 50X
- System diagram & detailed spec sheet available on Navitar website:

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

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



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Optem Fusion industrial microscope with EL-16-40-TC autofocus module

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

Liquid Lens Autofocus Module

Space saving liquid lens module provides fast autofocus capabilities without cumbersome motorized focus drives.

Simply inserts directly above the chosen Lower Function Module.

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

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Mvotem industrial microscope with EL-16-40-TC autofocus module

- The zoom is parfocal as the EL is placed below the zoom
- Lens driver fully integrated into system software

- Video: https://youtu.be/ZZFe3hg9JwM
- Website: www.mvotemoptics.com/automatic-zoom-lens.html

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 setting	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
Horiz. 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

Low cost AF microscope with fixed mag

C-mount camera

Empty C-mount tube,
40-60mm long

Optotune lens
EL-10-30-Ci-VIS-LD

M22 to C-mount adapter

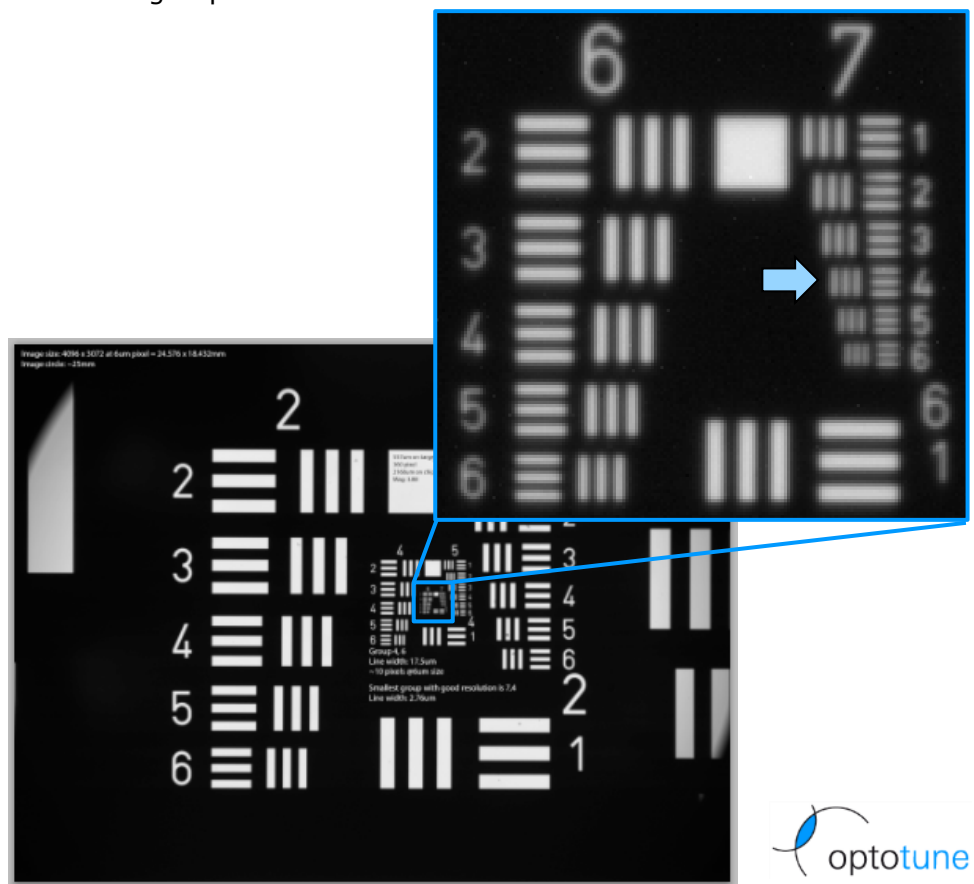
25mm lens (reversed!)
Edmund Optics 85358

Working distance: ~20mm

Tube length	40mm	60mm
Magnification*	3X	4X
Z-range:	~3mm	~2mm
Resolution:	3.7um	2.8um**
Image circle	25mm	25mm

* 5-6X can be achieved with a reversed 16mm lens

** Line width of group 7 element 4



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

- EL-10-30-Ci-VIS-LD-MV integrated

TECHSPEC® TUNABLE COMPACT OBJECTIVE LIQUID LENS ASSEMBLIES			
Magnification:	**2X**	**5X**	**Image**
Numerical Aperture NA:	0.12	0.15	
Working Distance (mm):	31.3	16.2	
Focus Tunable Range (typical) (mm):	±2	±0.5	
Maximum Sensor Size:	⅔"	⅔"	
Field of View, ⅔" Sensor (mm):	4.4 x 3.3	1.8 x 1.32	
Field of View, ½" Sensor (mm):	3.2 x 2.4	1.28 x 0.96	
Mount:	C-Mount	C-Mount	
Liquid Lens Type:	10mm, VIS Coated, -1.5 - 3.5 diopter range	10mm, VIS Coated, -1.5 - 3.5 diopter range	
Stock No.	#34-712	#34-713	
1-5	$950.00	$1,050.00	
6-10	$875.00	$975.00	
+11	**Call for OEM Quantity Pricing**		

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

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Rapidly increasing number of custom designs allow for optimized performance

In collaboration with our lens partners

Edmund optics | worldwide

VS TECHNOLOGY
MACHINE VISION OPTICS

SILL OPTICS

Kowa

NAVITAR

QIOPTIQ
Photonics for Innovation
An Excelitas Technologies Company

change 4 change

EVETAR®

LINKHOU

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12 mm lens with integrated EL-16-40 by VST

High resolution and **large field of view (FOV)** at the same time

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

Working distance (WD) range from 250mm to infinity

- Best MTFs in the range of 500 to 1000mm
- High optical leverage (1.13 m/dpt)

Resolution for 2.4um pixels (e.g. Sony IMX253/304 1.1” or IMX183 1”)

- 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
- Significant barrel distortion, which can be corrected digitally

ELM-12-2.8-18-C

25 mm lens with integrated EL-16-40 by Evetar

High resolution and **medium field of view (FOV)**

- Ideal for code reading (e.g. box packing), iris recognition

Working distance (WD) range from 250mm to infinity

- Ideal optical leverage of 0.61m/dpt

Resolution for 2.4um pixels (e.g. IMX183 1” or IMX304 1.1”)

- In the center over the WD range: at 169-180 lp/mm (close to Nyquist limit)
- At the corners for WD 250mm-1000mm still 157-174 lp/mm

Image quality

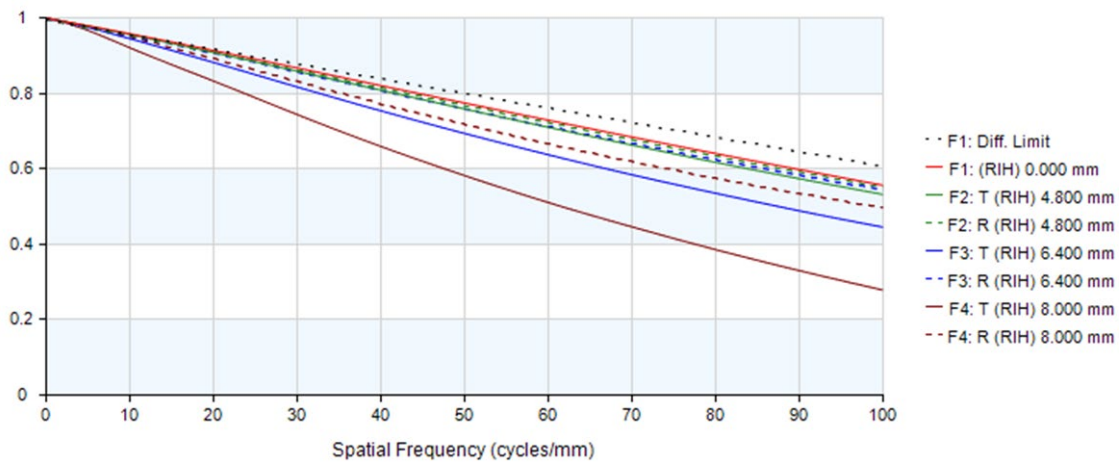
- No vignetting up to 1.1” format
- Very low distortion
- Great polychromatic (white light) performance although better contrast was achieved with monochromatic (red) light

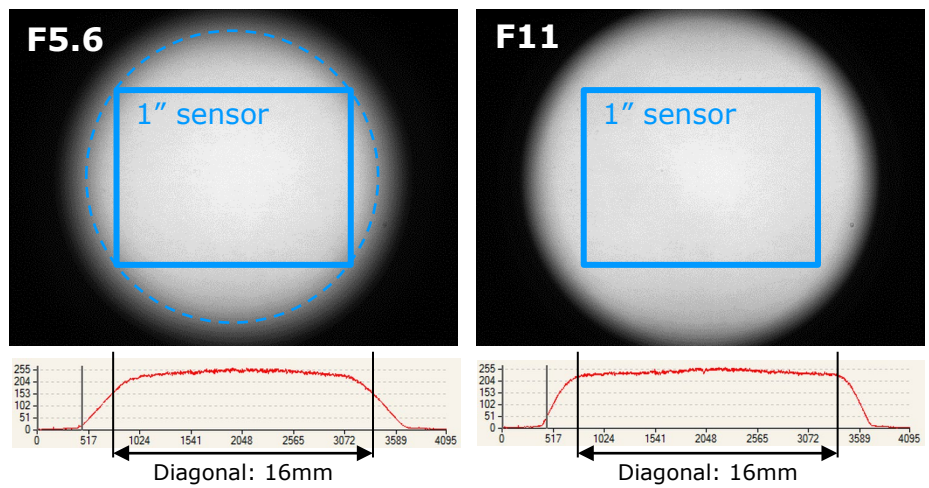
ELM-25-2.8-18-C

35mm lens for 1” sensors by Kowa

Optimized optical design provides top performance

- 1” camera sensors
- F5.6 to F32 (lower F# achievable with EL-16-40-TC)
- WD range: 250 – 500mm (250 – infinity achievable with EL-16-40-TC)
- MTF50 @ 80 – 120lp/mm
- No orientation dependence





Spec sheet: www.optotune.com/images/products/Optotune-Kowa_35mm_lens_S10-469_spec_sheet.pdf
Test report: www.optotune.com/images/products/Optotune_35mm_imaging_lens_for_1inch_sensors.pdf

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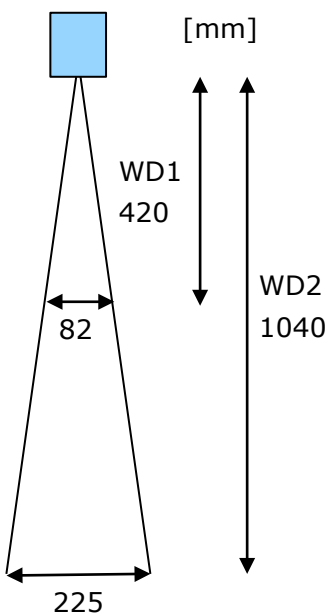
50mm lens for 1.1” sensors by C4C

- Optimal performance due to integration of the EL-16-40 lens close to the aperture stop
- Main specs:
  - Working distances: 285mm to infinity
  - Resolution: 140lp/mm (also with optical axis horizontal)
  - F-number: F/2.8 with some vignetting, F/4 without vignetting

- Test:



WD1 @ 3 Dpt:

Resolution 104 LP/mm (image)

10 mil barcodes very well resolved

WD2 @ -2 Dpt:

Resolution 114 LP/mm (image)

10 mil barcodes still well resolved

Test report: https://www.optotune.com/images/products/181213%20c4c_50mm_1p1inch%20%2B%20EL-16-40.pdf

optotune

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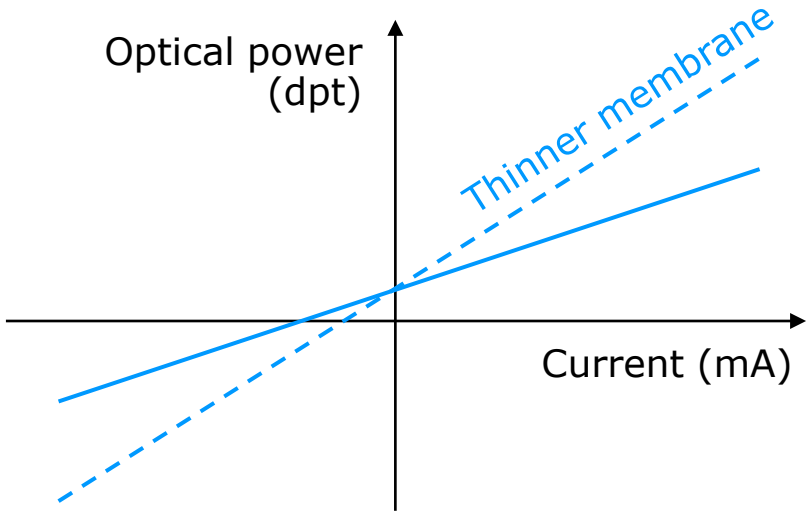
Optical power is measured in diopters

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

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:

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

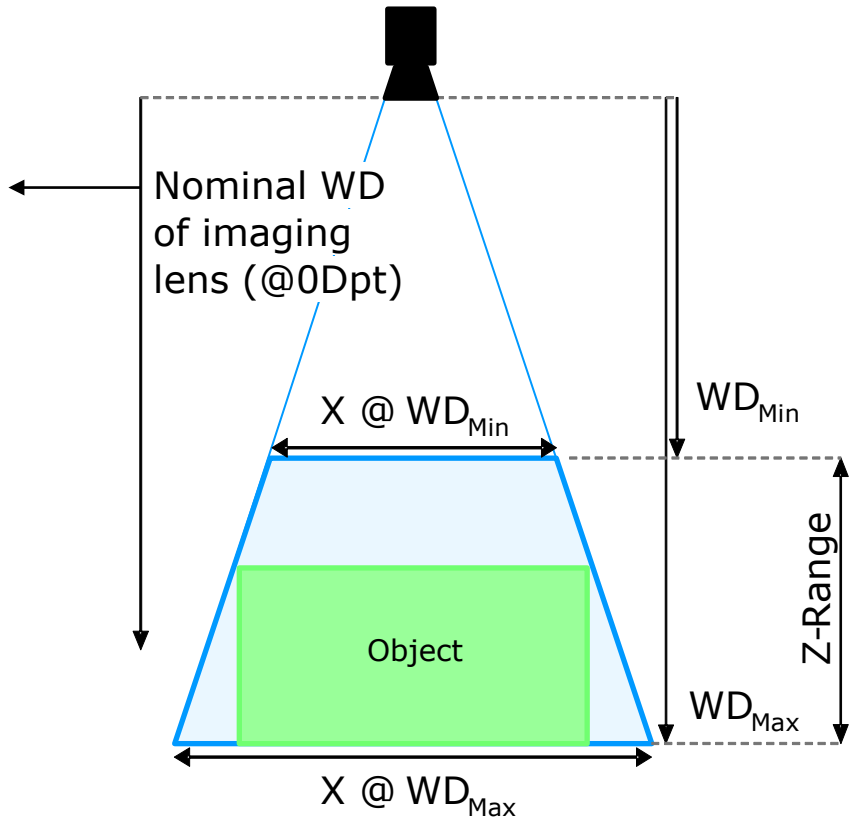
Examples:

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

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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The EL in front leads to vignetting at HFOV>28°

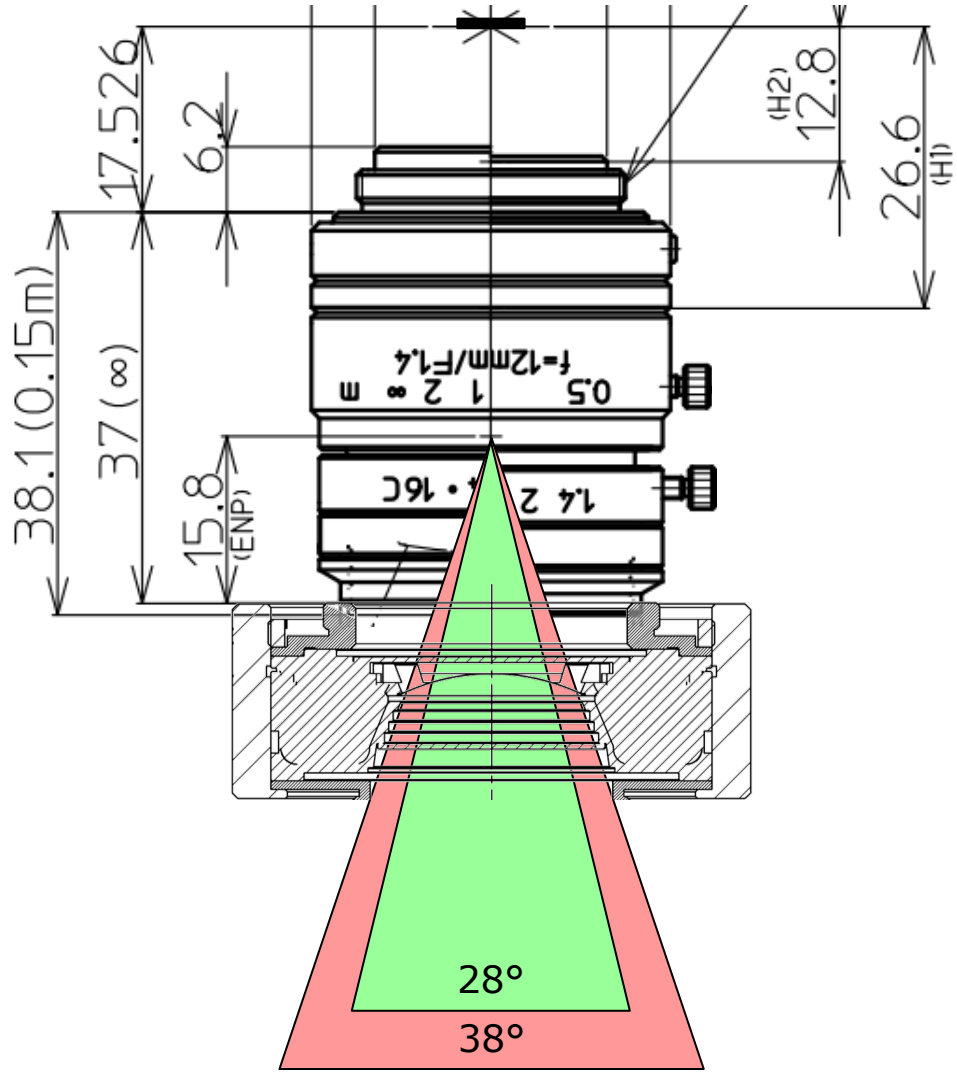
Front-lens configuration

C-mount
camera

C-mount lens
filter threads
M25.5 M27 & M30.5

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

2/3" 1.4/12mm C		2/3"	1/1.8"	1/2"
FOCAL LENGTH		f=12mm		
MAX. DIAMETER (RATIO)		F=1:1.4~Close		
PICTURE SIZE		6.6x8.8mm		
ANGLE	VER. ANGLE	29.1°	24.0°	21.4°
	HOR. ANGLE	38.3°	31.7°	28.3°
	DIA. ANGLE	46.8°	39.4°	35.0°



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Configuration table for entocentric lenses

Camera sensor	Mount	Imaging lens focal length (mm)										
		<6	6	8	12	16	25	35	50	75	100	>100
1/4”	S		30° HFOV	23°	15°	11°	7°	5°	4°	2.5°	2°	
	C											
1/3”	S		44°	33° *	23°	17°	11°	8°	6°	4°	3°	
	C							**Front- or back lens configuration**				
1/2”	S		56° *	44°	30°	23° *	15°	10°	7°	5°	4°	
	C											
2/3”	C		73°	58°	40°	31°	20°	14°	10°	7°	5°	
1”	C		74°	77°	56° *	44° **	29° *	21° *	15° *	10°	7°	
30mm diag.	M42		128°	114°	91°	75°	52°	39°	28°	19°	14°	
		Front lens configuration only					**Back lens configuration only**					

Not possible

Possible with custom optics design

Vignetting with off-the-shelf lenses

Possible with off-the-shelf lenses

* Custom design available

** Customized lens in development

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Online lens configurator for entocentric lenses

http://configurator.optotune.com

Optotune Lens Configurator

optotune

REQUIREMENTS

Please enter details about the objects you want to inspect.

Maximum object size

350 mm x 250 mm

Required working distance range

1000 mm to 3000 mm

OPTICAL CONFIGURATION

Camera sensor size: 1/2" - 6.4mm width

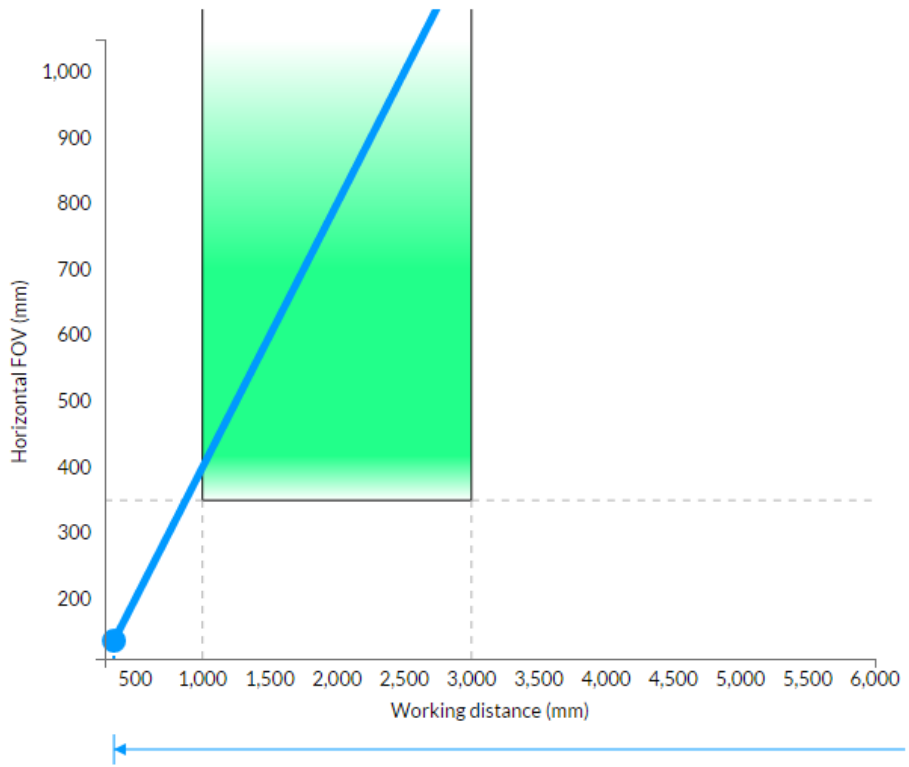
Optotune Lens: EL-16-40-TC-5D

Camera Lens: 16mm: Tamron 23FM16SP

Lens Configuration

- (•) Frontlens
- ( ) Backlens

Spacer: Millimeters 0 − +



Z-range: **Infinite**
Lens tuning range: **-2.0** to **3.0 dpt**

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Lens selector tool to get specific part numbers

http://www.optotune.com/Optotune lens selector.xlsx

Optotune lens selector for *endocentric* lenses

v17.05.2019

1) Enter your preferred average (nominal) working distance: 1000 mm
2) Enter the (horizontal) width of your object: 250 mm
   --> resulting horizontal field of view: 14 ° HFOV
3) Find an appropriate HFOV in the table and click to see a list of recommended lens configurations

Sensor format & camera		Imaging lens focal length (mm)										
		<6	6	8	12	16	25	35	50	75	100	>100
1/4"	S-mount		30° HFOV	23°	15°	11°	7°	5°	4°	2.5°	2°	
	C-mount											
1/3"	S-mount		44°	33°	23°	17°	11°	8°	6°	4°	3°	
	C-mount											
1/2"	S-mount		56°	44°	30°	23°	15°	10°	7°	5°	4°	
	C-mount											
2/3"	C-mount		73°	58°	40°	31°	20°	14°	10°	7°	5°	
1"	C-mount		74°	77°	56° *	44°	29° *	21°	15°	10°	7°	
30mm diag.	M42-mount		128°	114°	91°	75°	52°	39°	28°	19°	14°	
			Front lens configuration only				Back lens configuration only					

Not possible | Possible with custom optics design | Vignetting with off-the-shelf lenses | Possible with OTS lenses

1) Enter FOV and WD
2) Angular FOV is calculated
3) Click on a field in the matrix
4) Recommended imaging lenses and the matching Optotune product are listed

Note: Only for entocentric lenses

1" sensors & 35mm focal length

Back to overview

Imaging lens							Optotune lens				Typical WD range (mm)					
Brand	Model (incl. weblink)	Focal length	Mount	Format	Filter thread	List price range	Model	List price range	Position	Spacers behind EL for infinite WD	Nominal WD (w/ ETL 0 dpt)	WD max	WD min	Vignetting	Smallest recommended pixel size (um)	Test report available	Comments
Kowa	LM35HC-OPT	35	C-mount	1"	None	200-500$	EL-16-40-TC-VIS-5D-C	500-1000$	Back	NA	1'000	inf	200	No	3.5	Yes	Integrated design, very compact, great performance
Schneider	Xenon Topaz 30	30	C-mount	1.1"	M30.5x0.5	500-1000$	EL-16-40-TC-VIS-5D-M30.5	500-1000$	Front	NA	1'000	inf	200	A little	3.0	Yes	Hardly any vignetting on 1", a bit on 1.1"
Schneider	Xenon Topaz 30	30	C-mount	1.1"	M30.5x0.5	500-1000$	EL-16-40-TC-VIS-5D-M30.5	500-1000$	Front	NA	1'000	inf	200	A little	3.0	Yes	Hardly any vignetting on 1", a bit on 1.1"
Schneider	Xenon Topaz 38	38	C-mount	1.1"	M30.5x0.5	500-1000$	EL-16-40-TC-VIS-5D-M30.5	500-1000$	Front	NA	1'000	inf	200	No	3.0		Great performance up to 1.1"
Schneider	Xenon Topaz 38	38	C-mount	1.1"	M30.5x0.5	500-1000$	EL-16-40-TC-VIS-5D-C	500-1000$	Back	NA		88	67	No	3.0		
Optart	KMK3520-10M	35	C-mount	4/3"	M40.5xP0.5	On Request	EL-16-40-TC-VIS-5D-C	500-1000$	Back	NA		88	67	No	4.0		Works well as macro up to 1.1"
Optart	VMK3514-C	35	C-mount	1"	M46XP0.75	On Request	EL-16-40-TC-VIS-5D-C	500-1000$	Back	NA		88	67	No	5.0		

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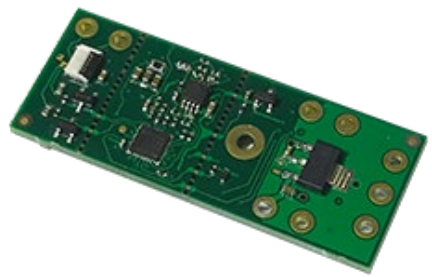
Optotune's liquid lenses for machine vision

	EL-10-30-TC	EL-10-30-C(i)	EL-16-40-TC
			
Focal power range	8 … 22 Dpt	-1.5 … +3.5 Dpt +5 … +10 Dpt	-2 … +3 Dpt -10 … +10 Dpt
Clear aperture	10mm	10mm	16mm
Outer diameter	30mm	30mm	40mm
Response time*	4 / 9 / 20 ms	2.5 / 6 / 15ms	5 / 12 / 25ms
Wavefront quality RMS @525nm**	<0.25 / 0.5 λ	<0.15 / 0.25 λ	<0.25 / 0.5 λ <0.25 / 1.5 λ
Absolute focal power accuracy (typical)	< 0.1 dpt	< 0.1 dpt	< 0.05 dpt
Typical use case	Microscopy	Small & mid size sensors	Large sensors

* 10-90% of step / settling time of a controlled step / settling time of rectangular step

** vertical / horizontal optical axis

Three drivers available off-the-shelf

	Optotune Lens Driver 4i	Gardasoft TR-CL180	Gardasoft CL191
			
Applications	R&D, portable systems	Industrial 24/7 operation	OEM
Current range	-290 to + 290 mA	-400 to +400 mA	-250 to +250 mA
Interfaces	USB	GigE, RS232, Analog 0-10 V	I2C, UART, Analog 0-10 V
SDKs	C#, LabVIEW	Triniti SDK, C#, C++, VB	C#, C++, VB
Supply voltage	5 V	24 V	3.3 or 5 V

Stable focus control with temperature feedback

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

Liquid lens stability

- Temperature drift of 0.02 - 0.06 diopters / °C (depending on lens model) is compensated by the driver
- Typical accuracy ± 0.1 diopter, which is usually within depth of field

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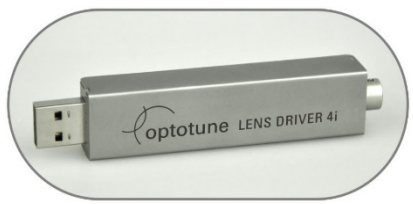
Lens control by camera removes the need for external drivers

Lens controlled by external driver

USB or Ethernet

Driver SDK

or



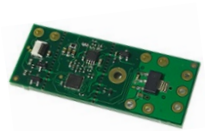
Lens current & I2C

Lens controlled via camera

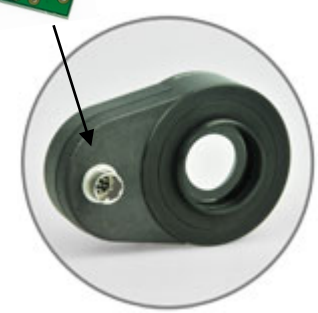
Camera SDK

Any interface

Power &
Serial interface



Integrated driver



To do: Provide serial interface & firmware for focus control

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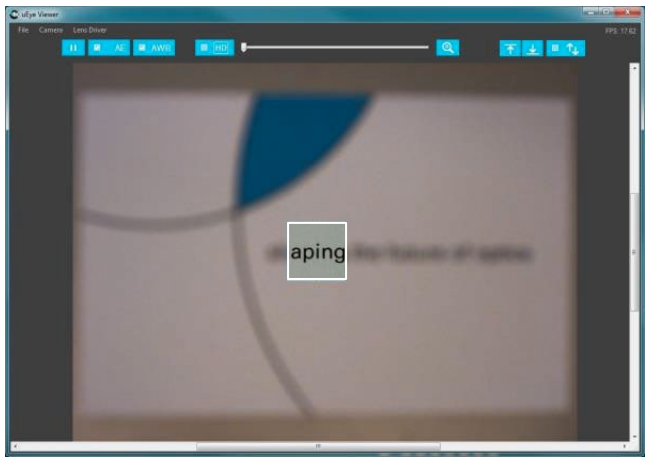
How to find the right focus

Image based autofocus

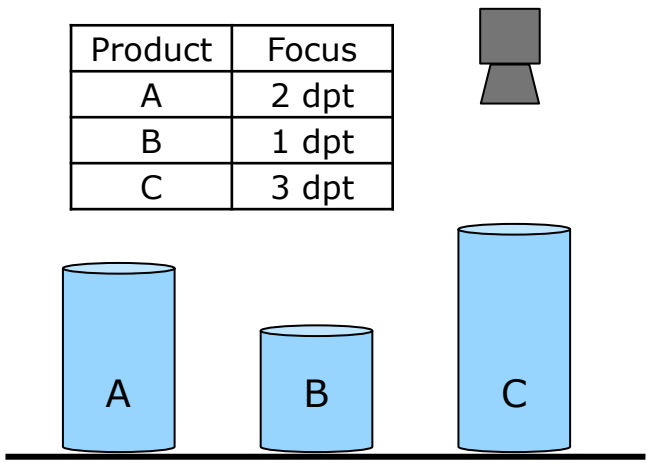


- Multiple images are acquired to find the best focus by algorithm
- Typically 10-15 frames required
  → 0.5 to 1 sec focus time

Cheap, flexible but not 100% reliable

Preset lookup tables

Product	Focus
A	2 dpt
B	1 dpt
C	3 dpt

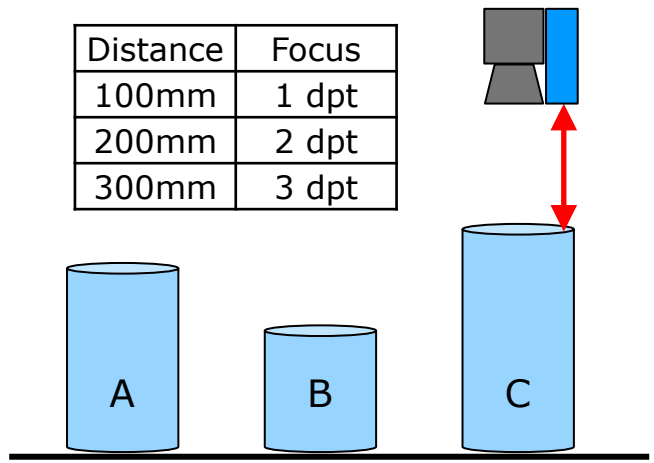


- Focus positions are stored in a lookup table during calibration (teaching)
- Only one focus step required
  → 15ms focus time

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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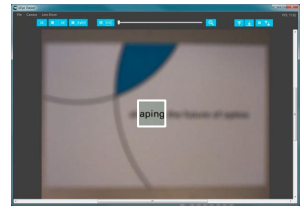
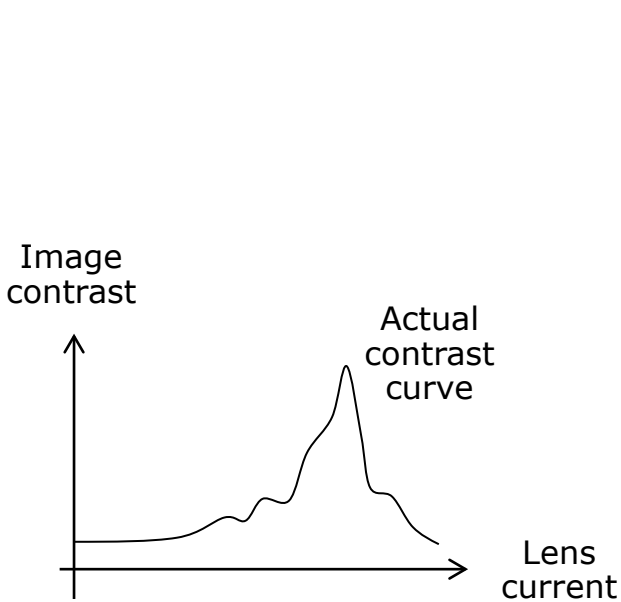
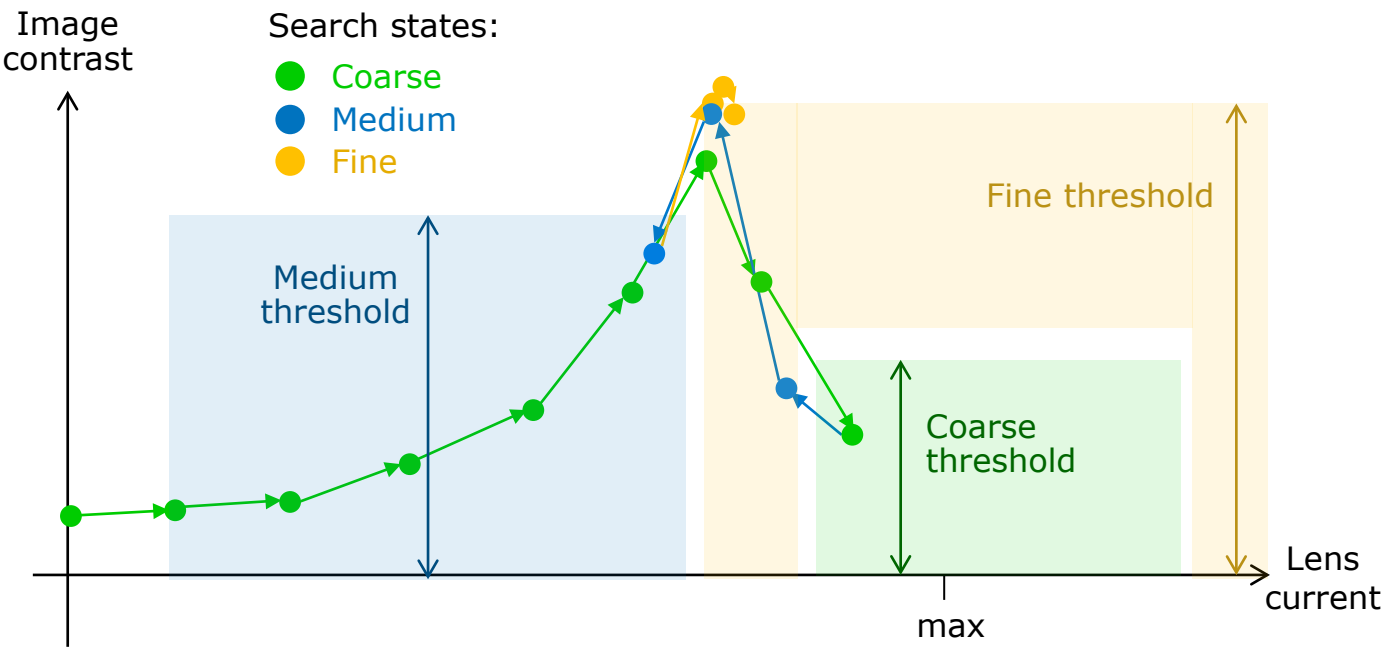
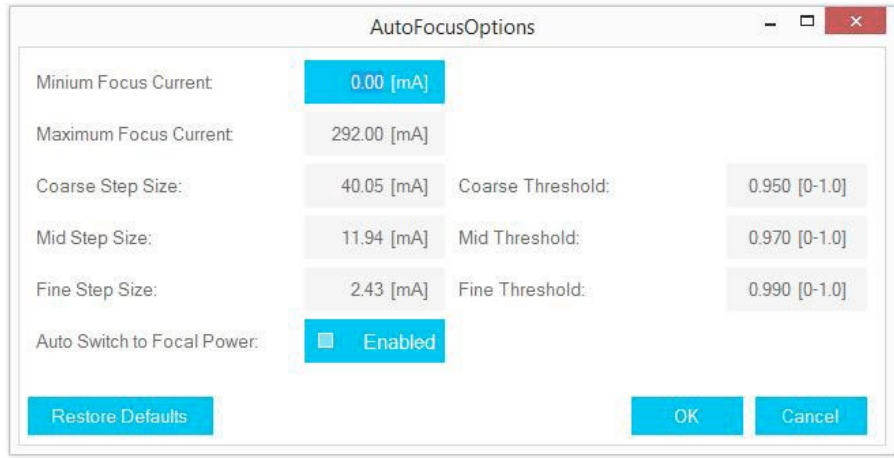
Optotune's autofocus algorithm







Parameters can be set in Lens Driver Controller:



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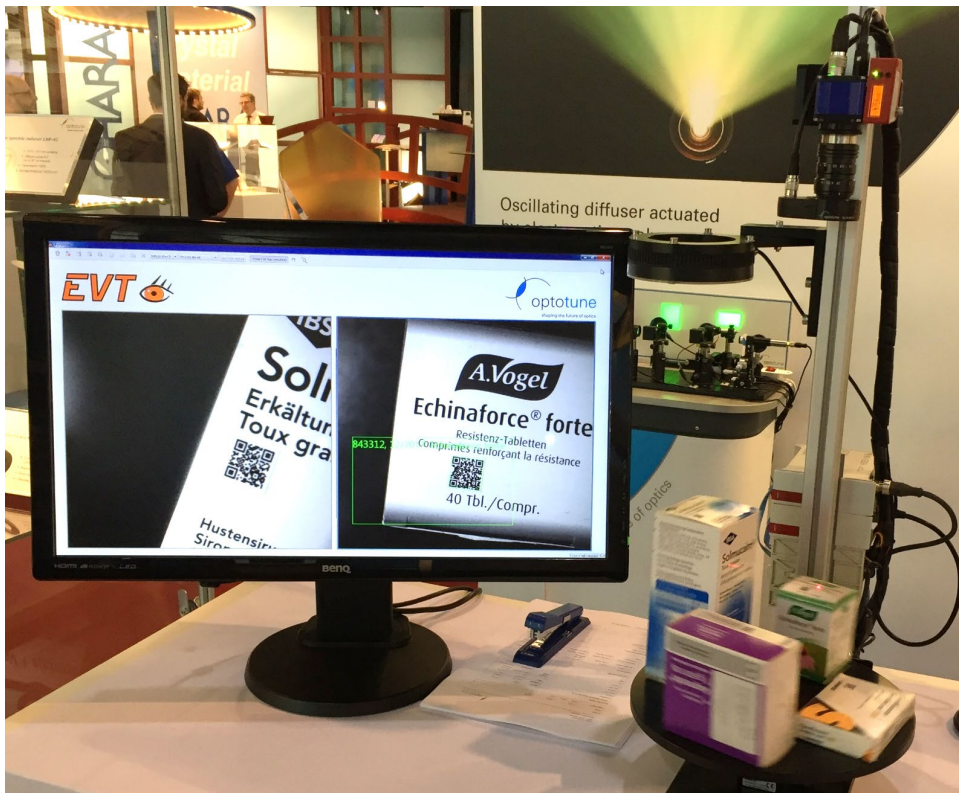
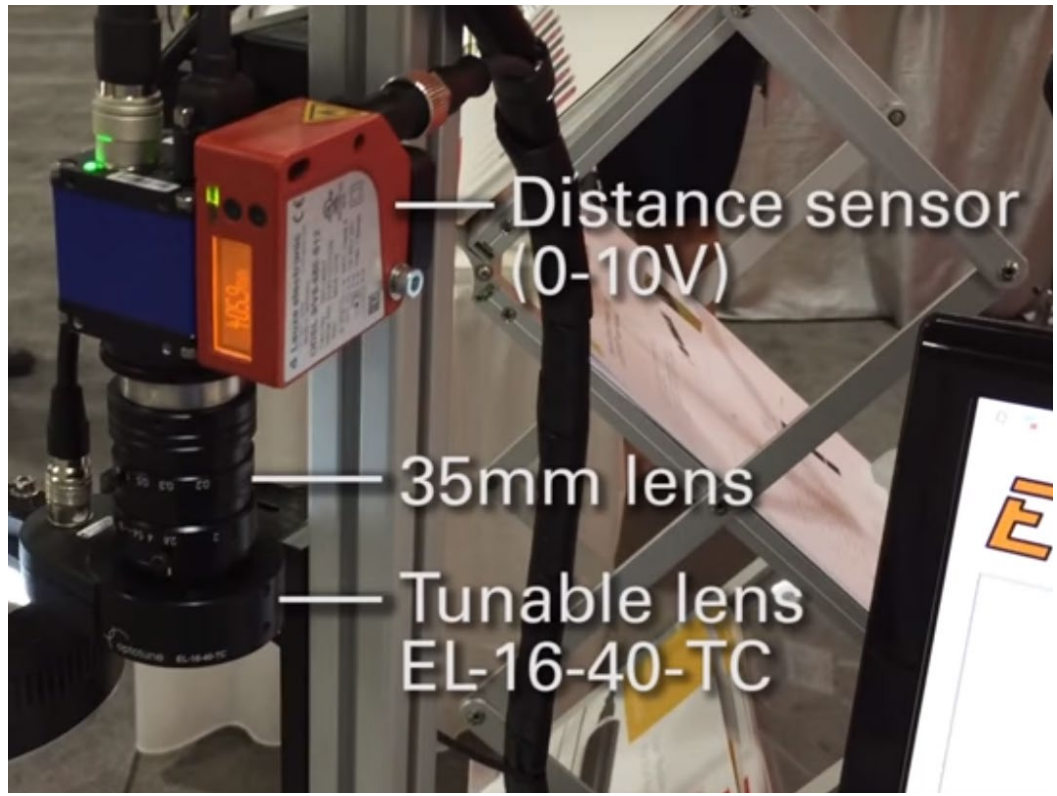
Example with distance sensor & Gardasoft driver





- 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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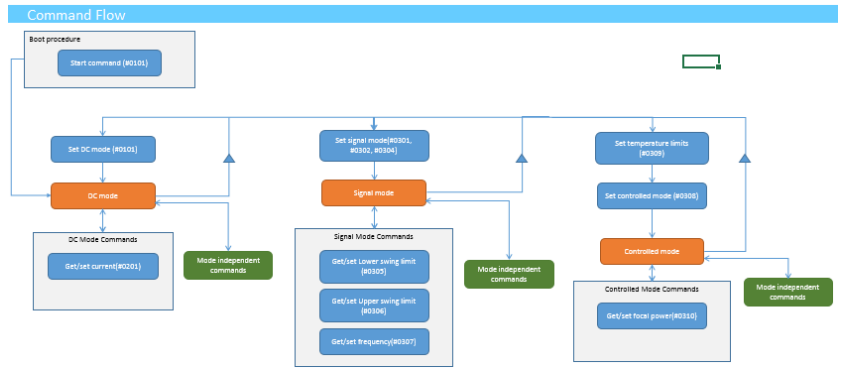
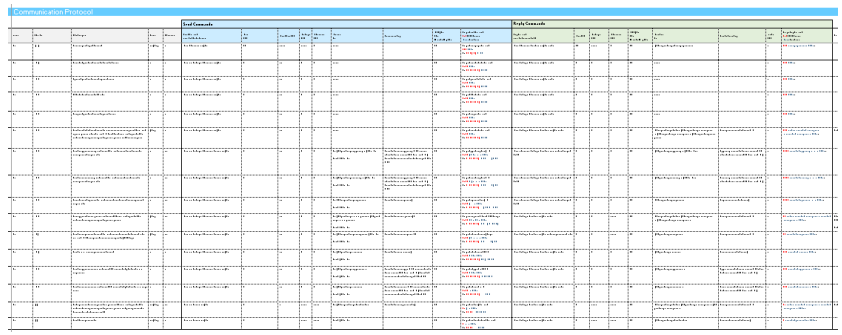
Lens Driver 4 serial protocol implementation

- Optotune's Lens driver is a serial device in Windows, Linux or using RS232
  - COM port in Windows
  - /dev/ttyACM0 in Linux
- Example commands are:
  - "Start" → "Ready" (works in ASCII)
  - SetCurrent
  - SetFocalPower
  - GetTemperature
- Implementation of a 16bit CRC is required
- Optotune provides sample code in C#, Labview, Python and Halcon

Command flow:



Serial protocol:



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Software partners for Optotune's Lens Driver 4

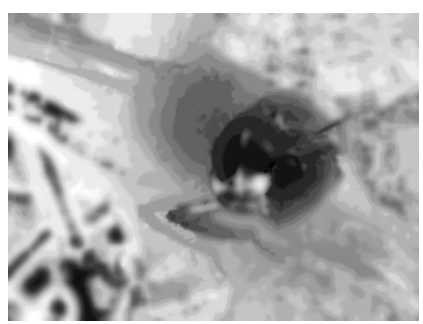
Partner company	Software	Integration features
	Common Vision Blox	- Lens Driver integrated in custom release - Slider for Focal Power Mode - Auto focus function
	EyeVision	- Lens Driver built in through plugin interface - User friendly integration of current mode - Auto focus function
	Halcon	- Lens Driver integrated via HDevelop procedure library - Source code can be edited - Image stacking & 3D reconstruction
	Matrox	- C++ project compatible with MIL10 - Auto focus implementation incl. "continuous mode"
	Modular X	- Lens control via DLL calls - Several autofocus functions incl. "continuous mode" - Image stacking & 3D reconstruction
	NeuroCheck 6.1	- Lens control via plugin-DLL - - Optical power mode - Parallel use of several lenses
	nVision	- Complete integration of all Driver features

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

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

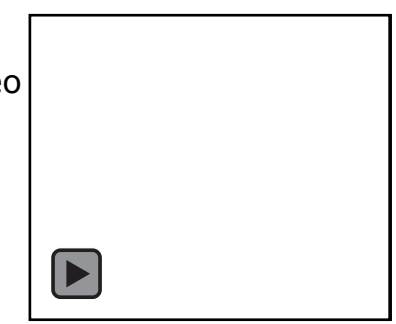
...

Rendered hyper-focus image**



Depth map

Video



*Ideally the number of frames to acquire is = Z-range / DoF **Rendered with Helicon Focus 6.7.1 software from 15 pictures (offline)

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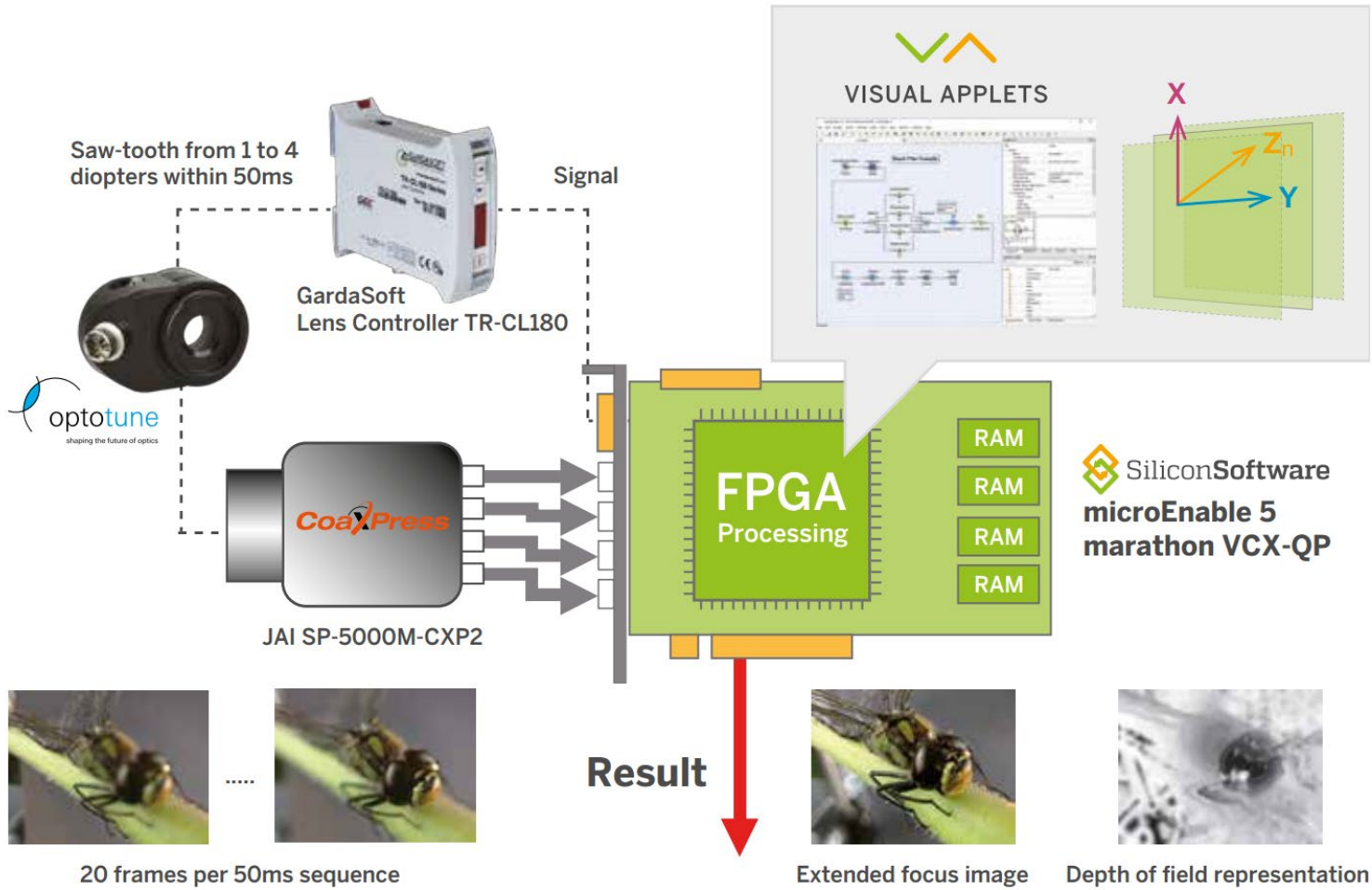
Focus stacking in real-time using FPGA

- 20 images per stack in 50ms
- Scaled & combined in FPGA with zero latency
- 1MP extended depth image @20fps
- The bottle neck is now the camera & camera interface



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

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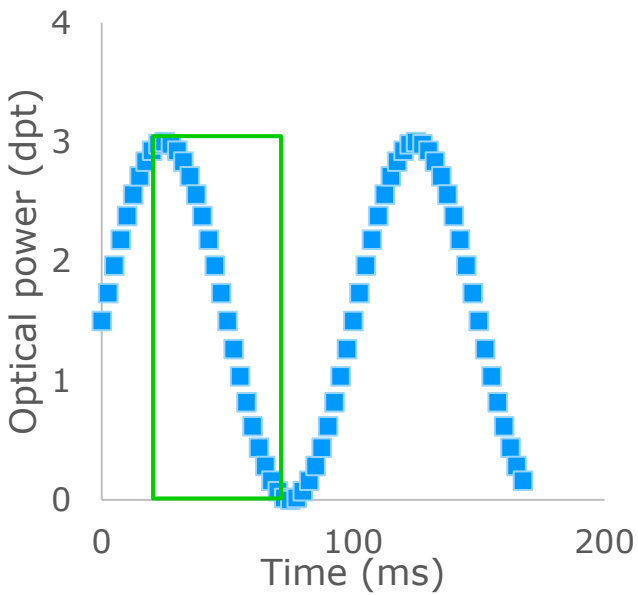
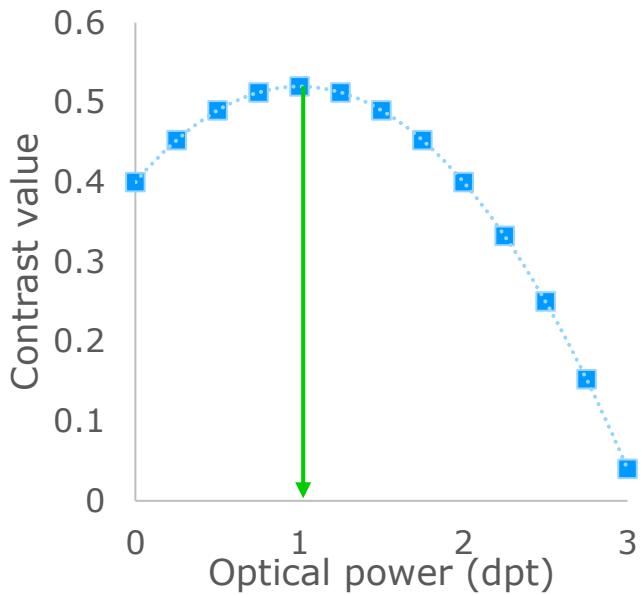
How to design a distance sensor based on DFF

1) Lens oscillation



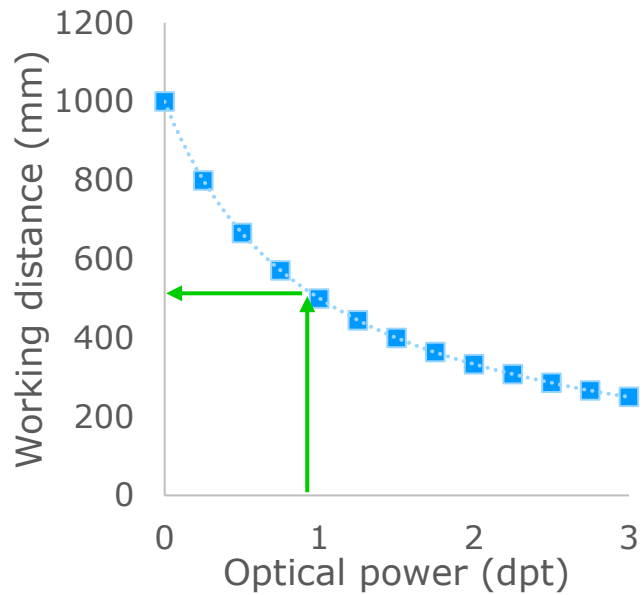
- Use a low-res camera with fast framerate (e.g. 400fps)
- Oscillate the EL at e.g. 10 Hz
- One sweep will contain 20 frames at different focus positions

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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Agenda

- Introduction
- How to combine ELs with off-the-shelf optics
  - Entocentric lenses
  - Telecentric lenses
  - Microscopy
- Custom designs
- Optics configuration tools
- Standard liquid lenses, drivers & software
- Application examples

Application example:

Package sorting – focus on different box sizes

- 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

Close focus

Focal length f:	60	mm	Field of view:	37	°
Sensor height v:	40	mm	Object height H:	533	mm
Working distance D:	800	mm	Magnification:	0.08	
Pixel pitch	5	um	Resolution on object:	67	um

Far focus

Focal length f:	60	mm	Field of view:	37	°
Sensor height v:	40	mm	Object height H:	1'000	mm
Working distance D:	1500	mm	Magnification:	0.04	
Pixel pitch	5	um	Resolution on object:	125	um

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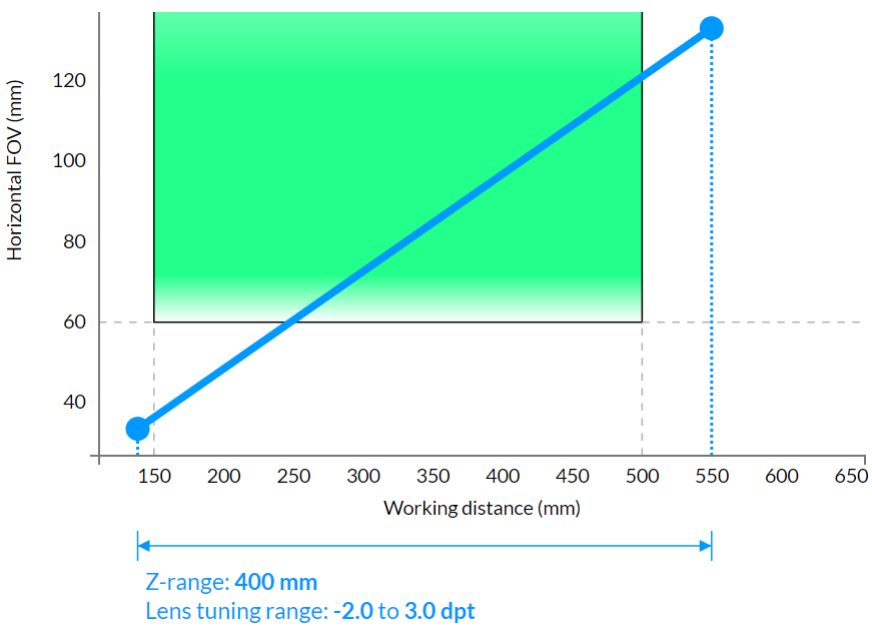
Application example:

Bottle inspection – refocus for different sizes

- 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



Z-range: **400 mm**
Lens tuning range: **-2.0** to **3.0 dpt**

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Application example:

Robot vision – refocus as you get closer to zoom in

- Camera mounted on robot arm
- Benefit: Focused images can be taken at any distance resulting in variable magnification. E.g. reducing WD from 1m to 0.2m + refocusing results in a 5X zoom!
- 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

Website: https://www.neurocheck.com/machine-vision-solutions/application-areas-2/robot-control-2/

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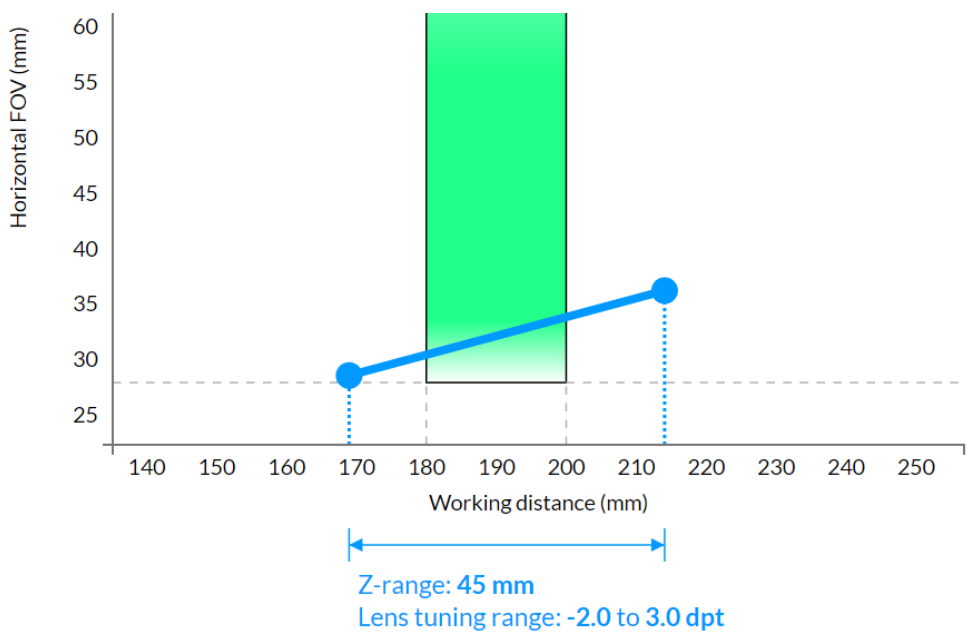
Application example:

Contact lens inspection – scan along the curves

- 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
- Resulting 3D FOV: 28x21x**45**mm



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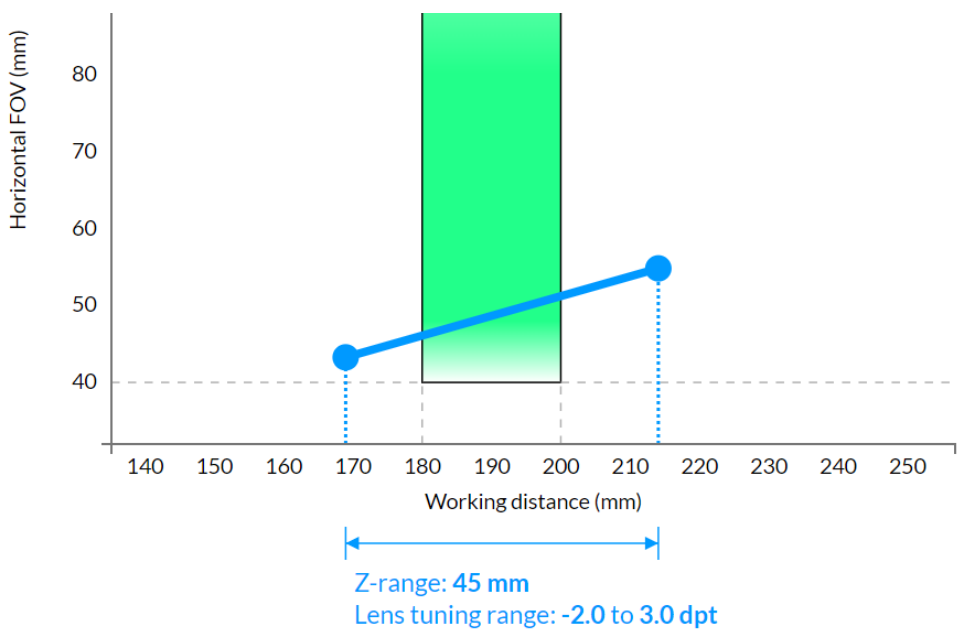
Application example:

Electronics inspection – fast autofocus

- Inspection of electronics, EL allows for continuous focusing
- Sensor size: 1”
- Tunable lens: EL-16-40-TC-VIS-5D-C
- Imaging lens: 50mm C-mount
- Resulting 3D FOV: 40x30x**45**mm



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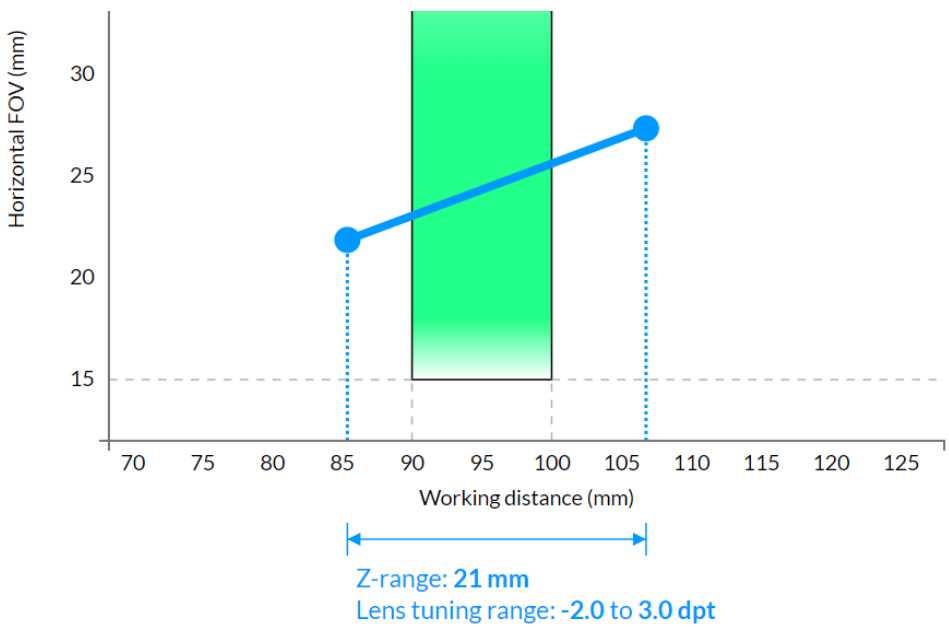
Application example:

Jewel inspection – scan through to find defects

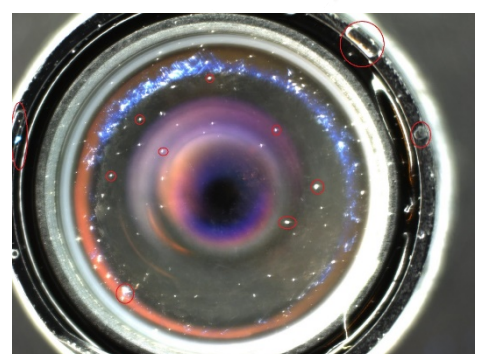
- Inspection of jewels (z-scan to find defects)
- Sensor size: 1”
- **Distance rings: 20mm**
- Tunable lens: EL-16-40-TC-VIS-5D-C
- Imaging lens: 50mm C-mount
- Resulting 3D FOV: 24x18x**21**mm



Application example:

Camera lens inspection – step through the stack

- 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 (integrated)
- Resulting 3D FOV: 14.2x10.4x**14.3**mm
- Test report available:
  https://www.optotune.com/images/products/181010%20VS-THV1-110-LQL1%20+%20EL-16-40-TC-VIS-5D-C.pdf



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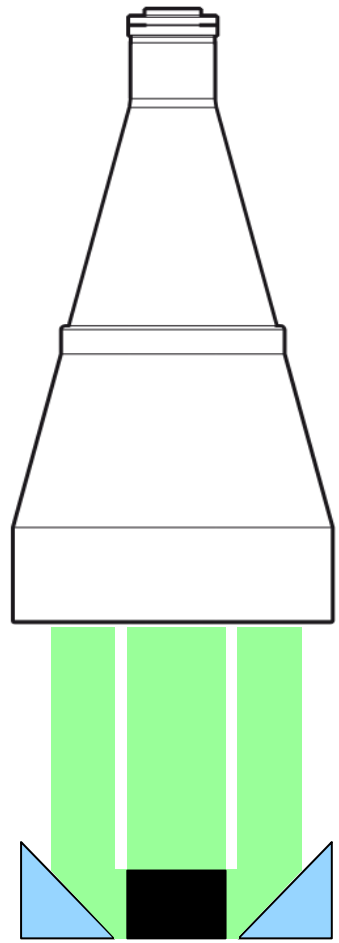
Application example:

IC inspection – image five sides with one camera

- Inspection of ICs, top and side views (via mirror) have different working distances
- Sensor: 1/2"
- Imaging lens: 0.15X telecentric lens
- Tunable lens: EL-10-30-Ci-VIS-LD (integrated)
- Resulting 3D FOV: 41.2x30.9x**50+**mm



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Application example:

Industrial microscopy – automated zoom & focus

- Lens control fully integrated into system software
- Tunable lens: EL-16-40-TC-VIS-5D-C
- Video: https://youtu.be/ZZFe3hg9JwM

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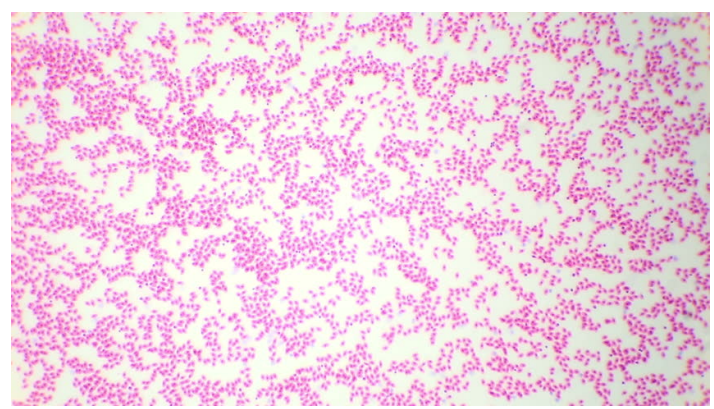
Application example:

Blood analysis – portable microscope

- 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
- Resulting 3D FOV: 1.4x1.1x**0.8**mm



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Thank you!

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shaping the future of optics

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