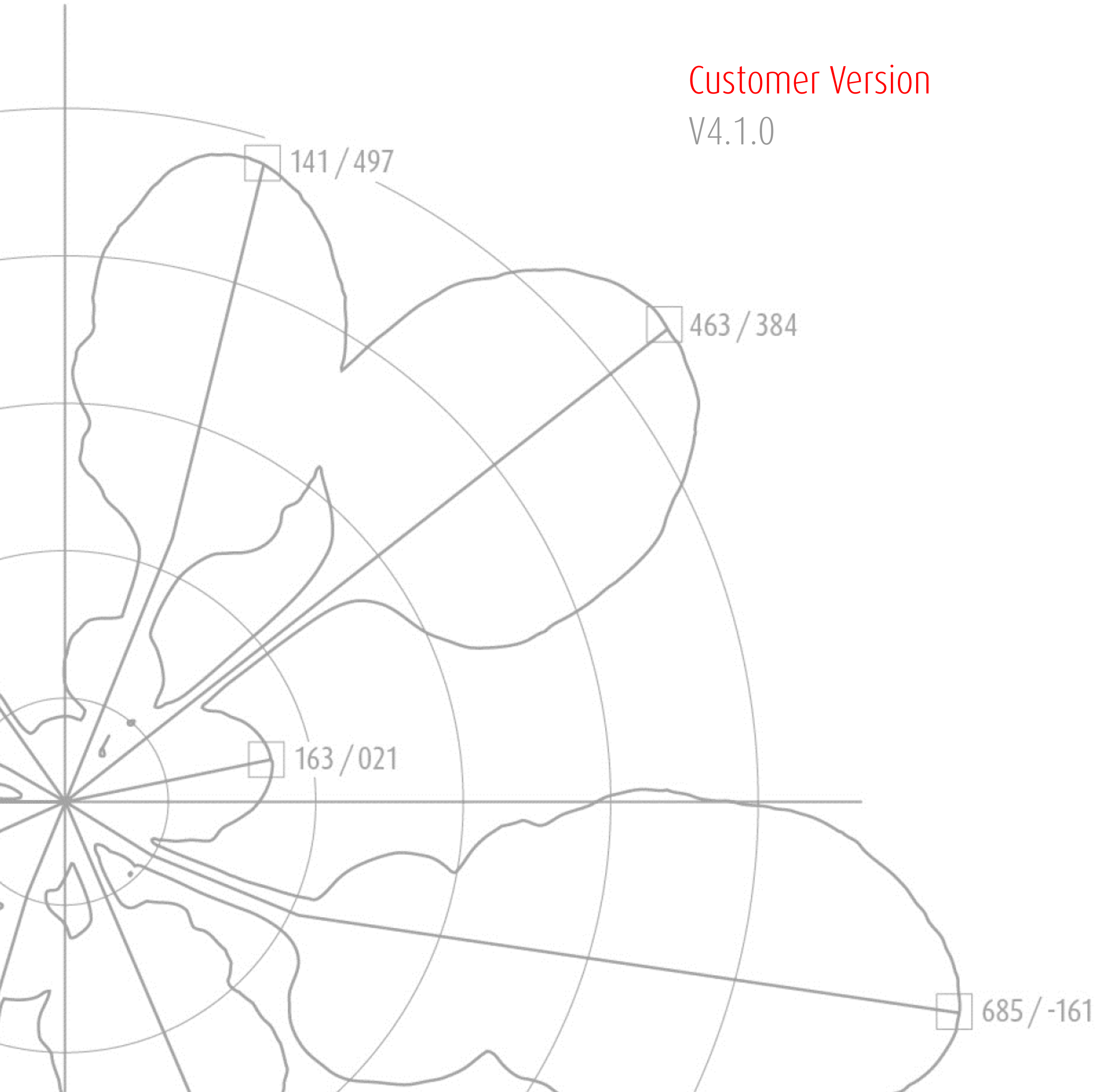
Stereo camera

Specification and rationale of a stereo camera system for LemnaTec Scanalyzer Field

Customer Version

V4.1.0



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1 Introduction

The following text provides a first set of information on concept, rationale and details of the stereo camera of the Scanalyzer Field system. The aim of the document is to provide clarification and to identify unaswered questions.

If further questions remain please do not hesitate to contact LemnaTec.

2 General approach

The stereo camera system is designed to provide a maximum of flexibility. Allowing the change of the orientation and angle based on the image analysis algorithms to be applied by the user group. Placed in an air conditioned container, the cameras are mounted on a pre drilled base plate for a precise and flexible mounting. To ensure highly reproducible imaging conditions for each pair of cameras, all cameras have a manual iris and focus. Once configured the camera geometry is mechanically fixed allowing.

The cameras will be triggered by an external signal ensuring a simultaneous image capturing.

The cameras mounted on the portal will be oriented horizontally and will be triggered the system is moving in x direction., the downward looking cameras will be triggered during the y movement of the camera box. The image pairs will be stored in the database together with the corresponding time and location stamp. Currently LemnaTec does not offer a solution to generate depth information from stereo images, however LemnaTec encourages the end user to analyze the images and will support the development and later integration into the image Pipeline. LemnaTec suggests the use of OpenCv for this task as it has prebuild functions for stereo imaging available.

3 Camera systems and mounting in the gantry system

3.1 General overview (top and side mounting)

The schematic drawing shows the top stereo system positioned in the main camerabox facing downwards to the field and the two side imaging systems facing horizontally into the field.

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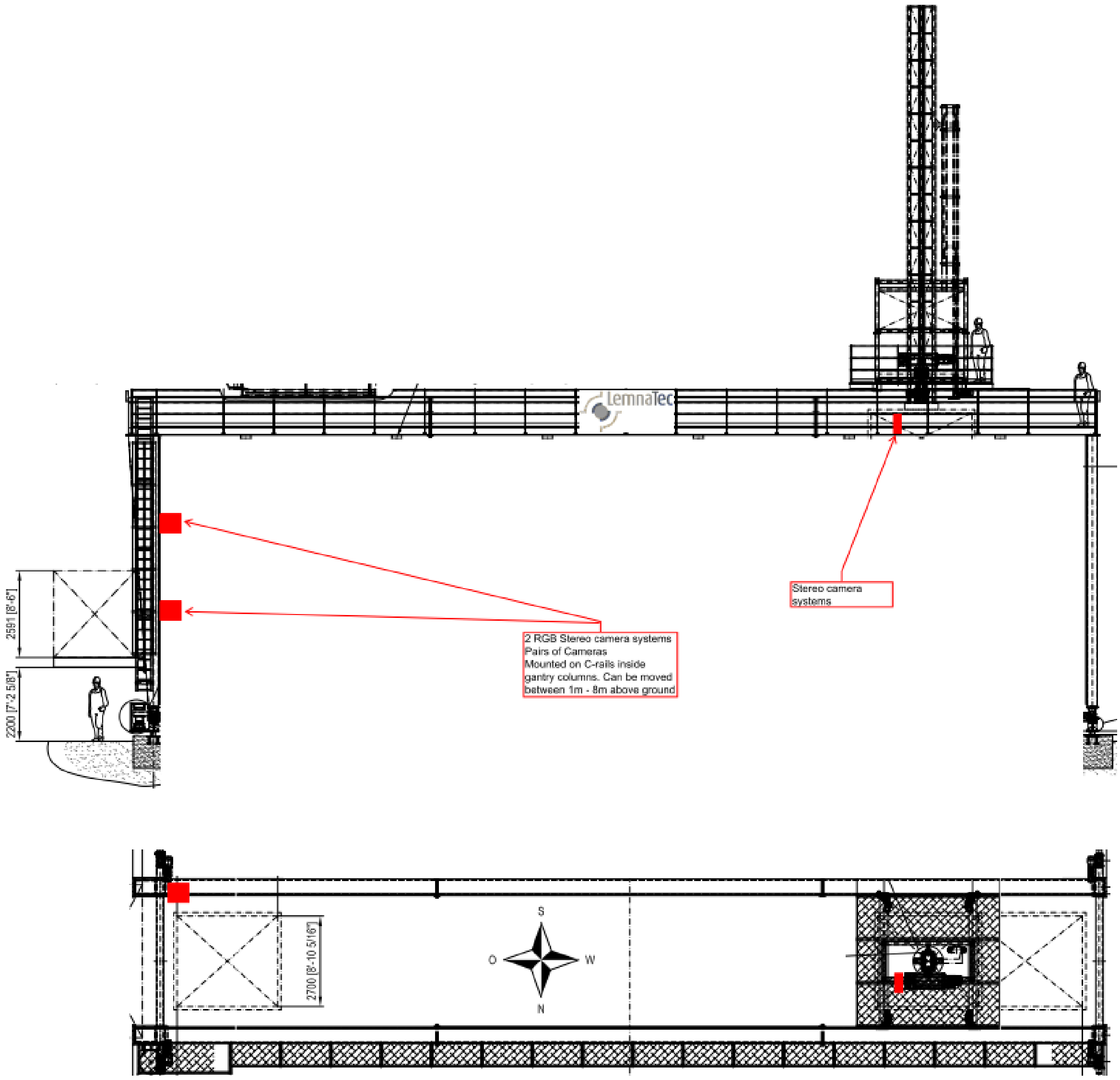

Figure 1: Side view (top picture) and top view (bottom picture) on the gantry system including the positions of the 3 stereo camera systems (SCS).

Side looking cameras are mounted with the long side of the image vertically allowing a maximum coverage of the plants to be imaged. Camera units can be moved manually on C-rails between 1 and 8 m height. The cameras can be mounted either on the east or west side portal, as well as having on pair east and one west.

3.2 Imaging geometry top camera system in the main camerabox

3.2.1 Top stereo cameras

The camerabox for all the top sensors is shown in the figure below. The arrangement of the sensors in the camerabox is optimized to offer the best results.

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The stereo cameras are marked in orange. In the description of the image field the distance between the optical axes of the stereo cameras is 150 mm axially parallel (in fact this can be modified as explained later on).

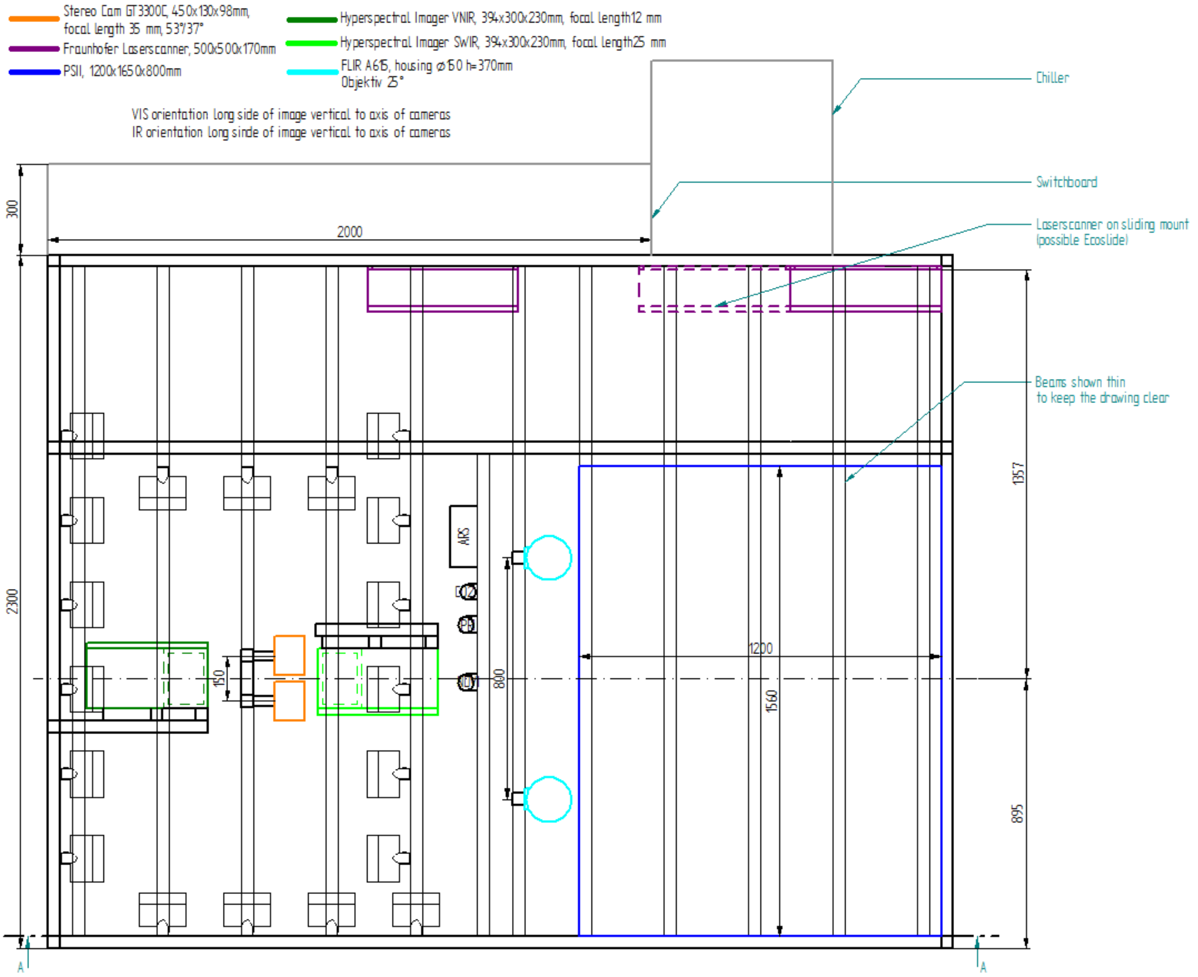

Figure 2: Top view camera box. The orange rectangles represent the stereo camera unit including two cameras in one box

The stereo camera system (SCS) is positioned in the centre of the artificial light field between two hyperspectral cameras on the main optical sensor axis (dotted horizontal line).

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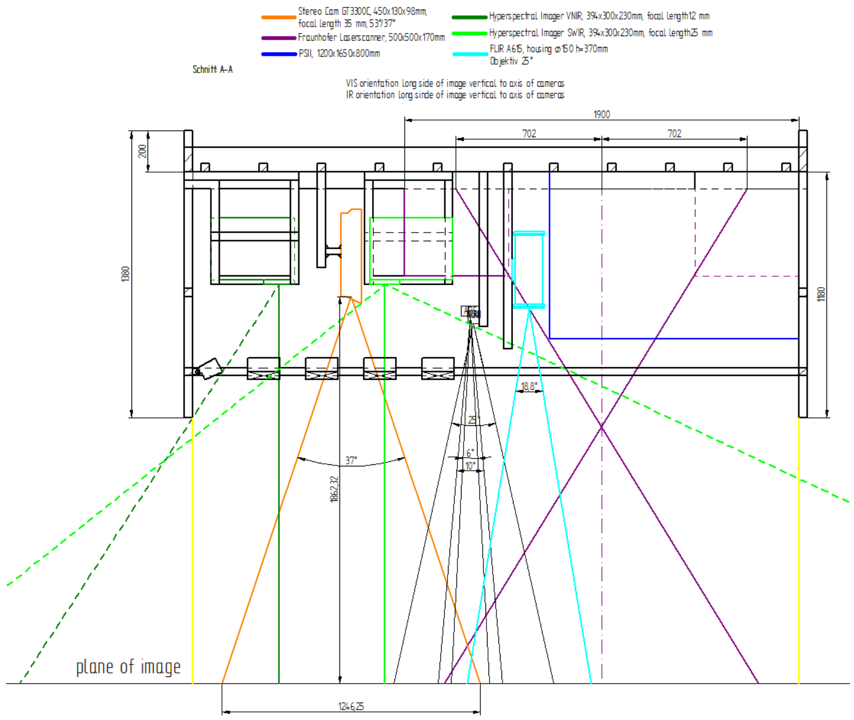

Figure 3: Side view camera box with angular field for all cameras. The SCS is shown in orange. The plane of image represents the Field of view of the corresponding cameras.

The angular field of the sensors is shown in the figure below in the left side view of the camera box.

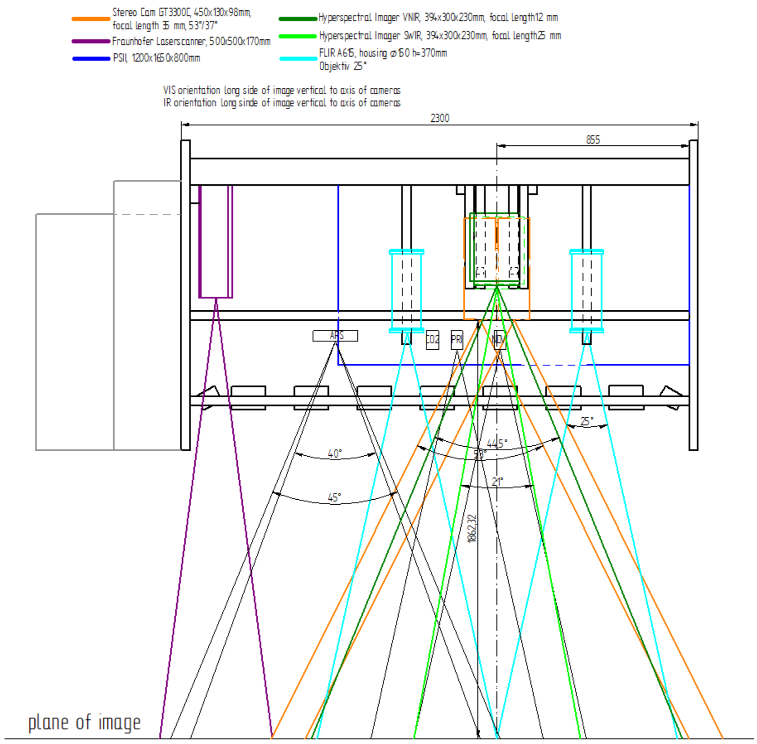

Figure 4: Left side view camera box with angular field for all cameras. The SCS is shown in orange.

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The following picture shows the top view of the camera field of views as overlays. The orange rectangles represent the stereo camera overlaps in case the both cameras are mounted with 150mm axial distance.

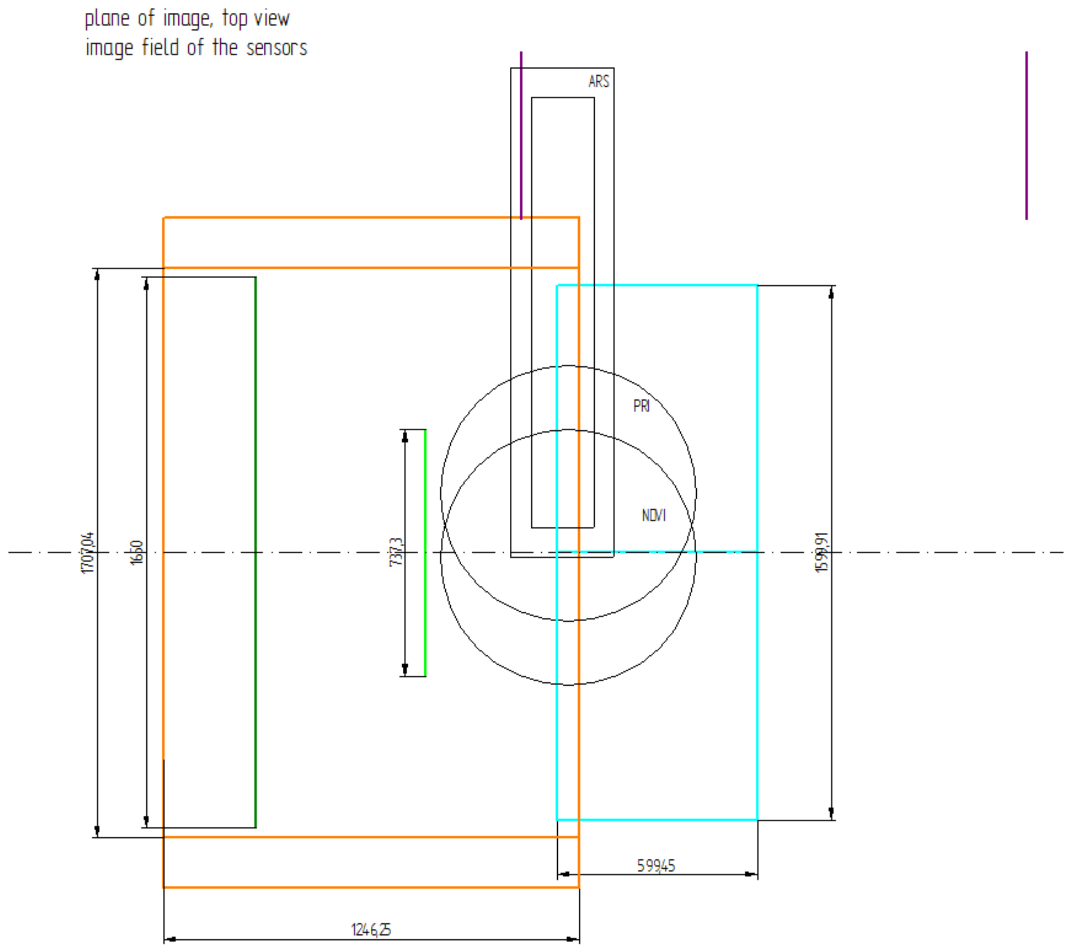

Figure 5: Image field of the sensors. The SCS is shown in orange visualizing the overlap zone for a 150 mm axial distance of the cameras.

3.2.2 Side looking stereo cameras

The side looking stereo camera systems have a different field of view due to of the distance to the object and different objectives which were selected to optimize size of the image and resolution.

More details to the objective see below.

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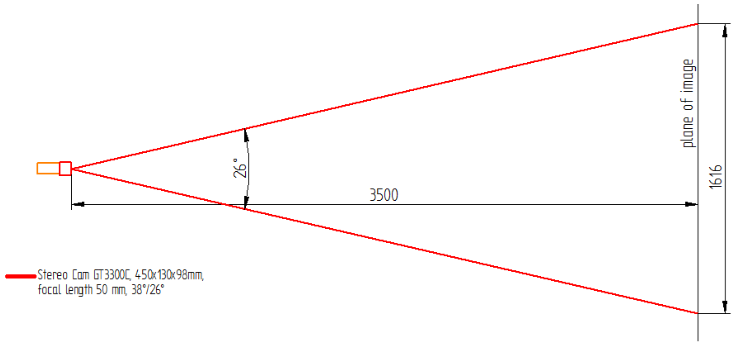

Figure 6: Top view of the side looking cameras (focal length 50 mm). The image of the cameras will be approx.1600 mm wide.

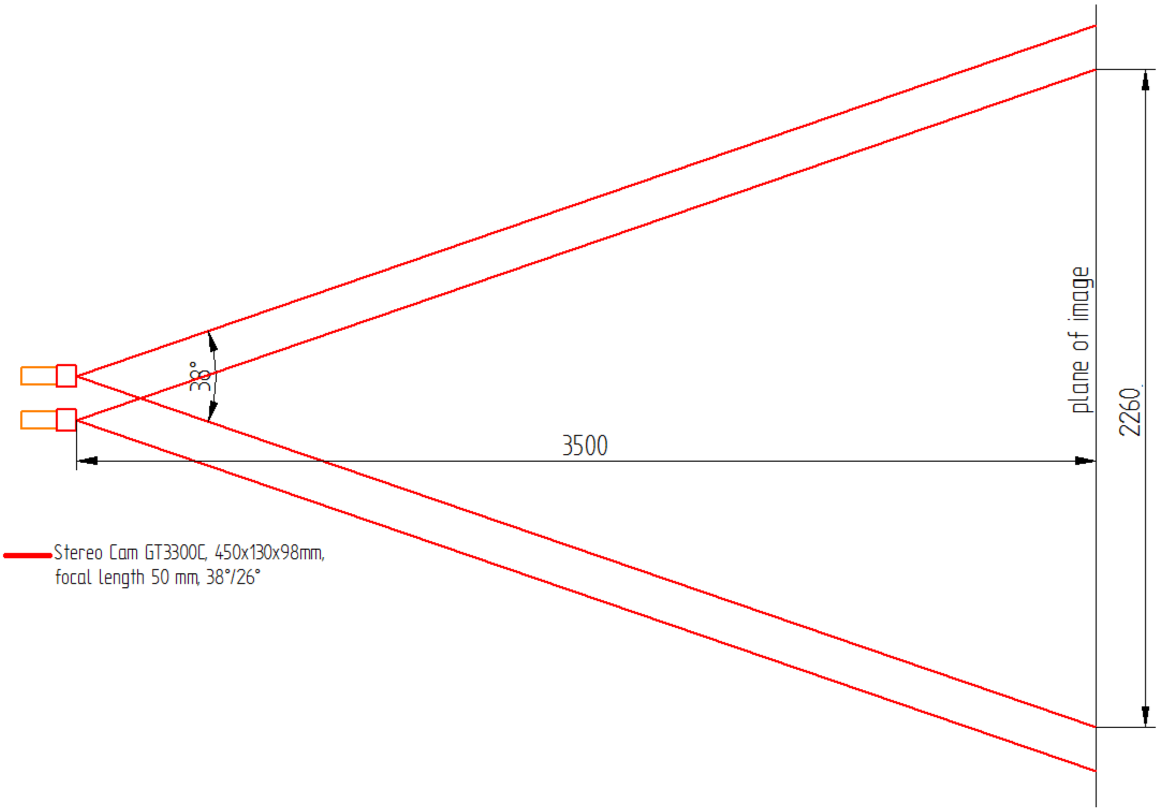

Figure 7: Side view of the side looking cameras (focal length 50 mm). The overlap image of the cameras will be approx. 2600 mm high (at a camera distance of 150 mm axial orientation)

4 Camera housing

4.1 Stereo camera system housing

The housing and the mounting of the stereo cameras will be the same for the top and side looking stereo cameras. The SCS will be placed in a water tight metal box with a glass window in front of the cameras. The drawing below shows approximate sizes of the box.

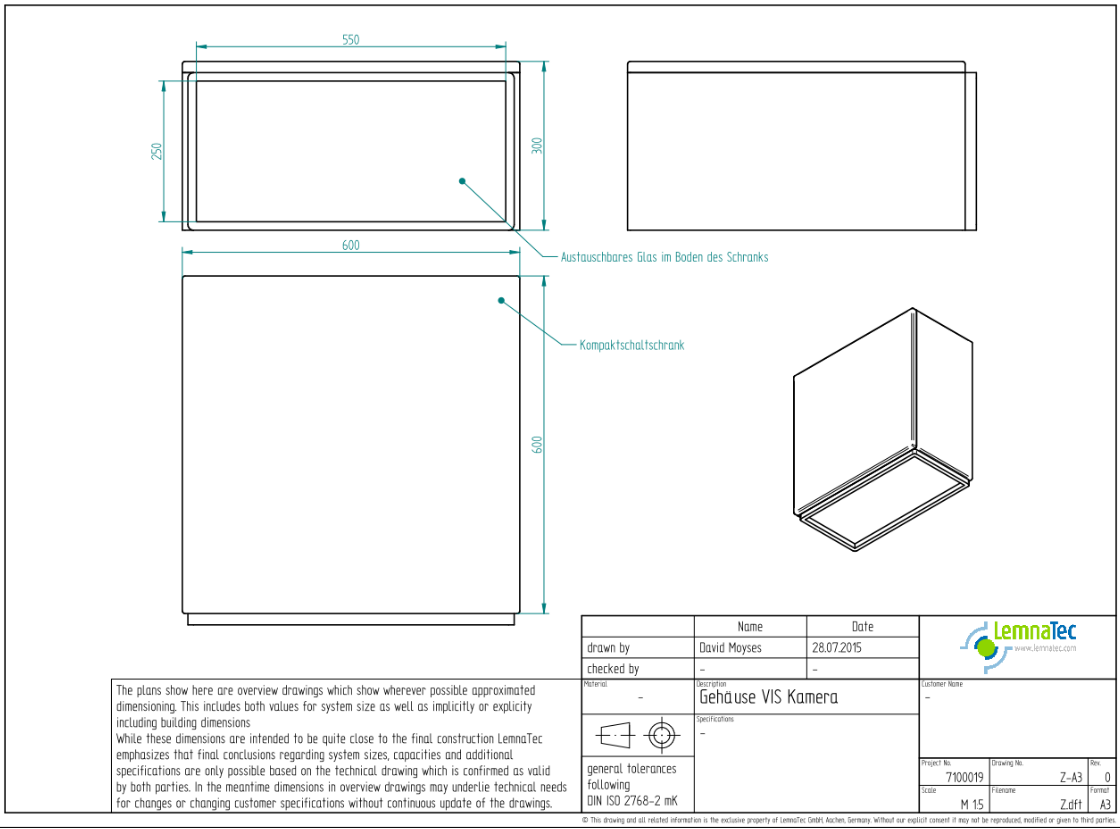

Figure 8: Housing of the stereo camera system including approximate sizes in mm.

4.2 Cooling

While the cameras have a general specification of up to 60 °C environmental temperature the boxes will include a Peltier cooling element to control temperature within the box well below 60 °C to ensure safe operations of the cameras.

The box housings will be insulated internally to minimize the sun induced heat load into the camera box.

4.3 Rationale of the camera mounting

There are different concepts for producing base image pairs for stereo vision and stereo analysis.

While the theoretical concept is much simpler for axial orientation of the cameras, convergent orientation is the standard case.

The LemnaTec system allows both options to the free selection of the user.

The distance between the optics center axes is another important parameter. While human vision works at a distance of 55 and 80 mm with DOFs in the range up to 10 m.

The SCS allows selecting a wide range of optics center axes distances which can be helpful for optimizing computational stereovision.

4.4 Mounting plate of the cameras and options

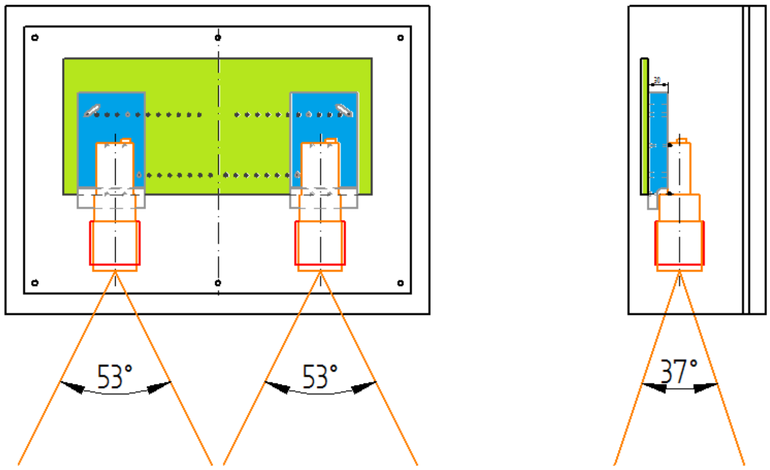

Figure 9: Schematic housing of the stereo cameras including the mounting plate (green) and the camera plates (blue) for mounting the cameras (orange) and objectives (red). Details on the base plate geometry are explained below.

There are two different plates designed for a proper camera mounting: A mounting plate and a camera plate. Using both plates in combination gives the ability to mount the stereo cameras in different positions and angles for adjusting the distance between the camera optics and different levels of convergent view.

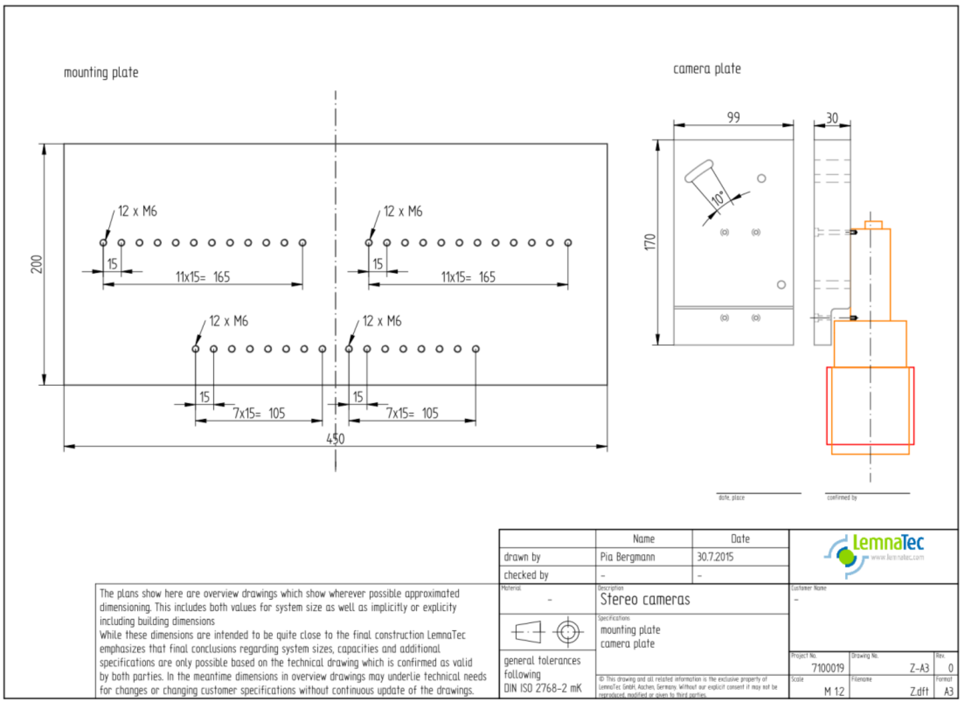

Figure 10: Stereo cameras mounting and camera plates. The mounting plate is made of an approx. 15 mm stable steel plate with a planar surface. The camera plate is made from the same material.

4.4.1 Mounting options general

There is an upper and a lower line of precisely threaded holes in the mounting plate. The center-to-center thread pattern distance on the mounting plate of both hole lines is 15 mm. The hole pattern in the camera plate includes a hole fitting to the lower line of the mounting plate, which represents the rotary center. For the 2nd fixing two alternatives area available:

1. An upper hole, which allows installing the camera plate to mount the cameras axially parallel. In this case the 3. hole, a long hole can be used for further fixation.
2. When using the long hole of the upper hole line only, the camera can be turned up to 10° to the vertical reference.
3.

The minimum mounting distance between the camera objective is 90mm, the maximum distance is 300mm in the current design.

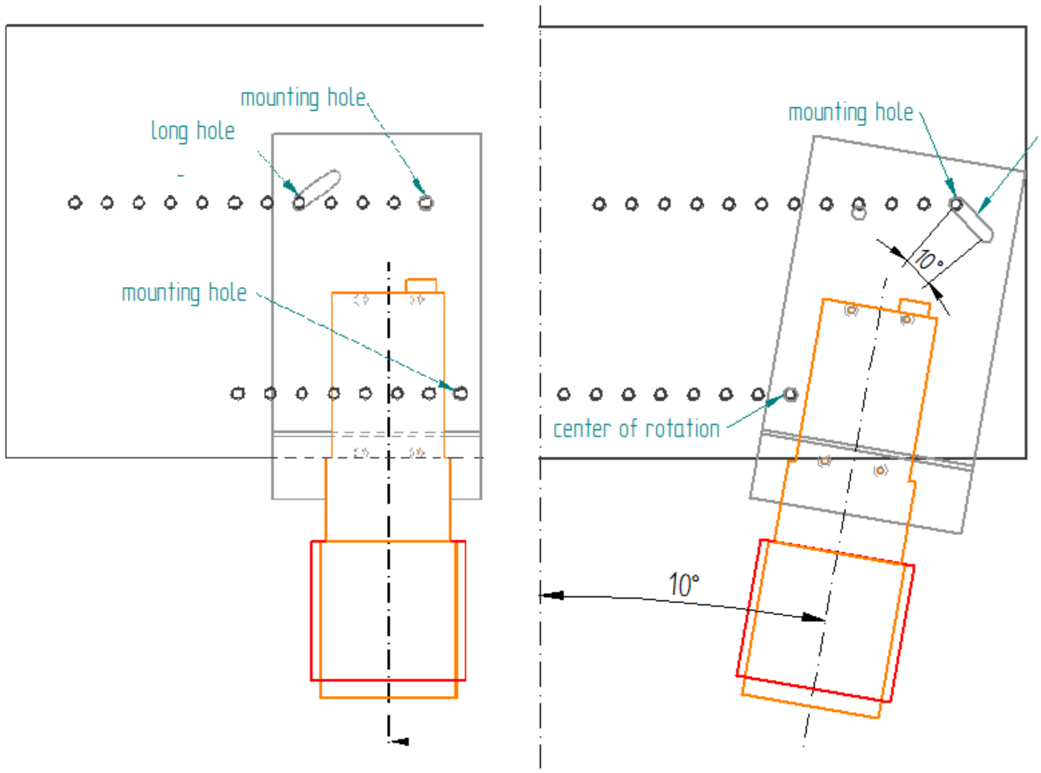

Figure 11: Camera mounting options using different holes

Minor adjustment to planarity can be done by thin metal sheets between the two plates.

4.4.2 Mounting options - Axially parallel

The maximum distance between the camera axes is 300 mm. The mounting holes are marked in the figure below. With two mounting holes it is guaranteed that the two cameras are axially parallel. The third possible mounting hole is just to fix the camera plate and is not mandatory necessary.

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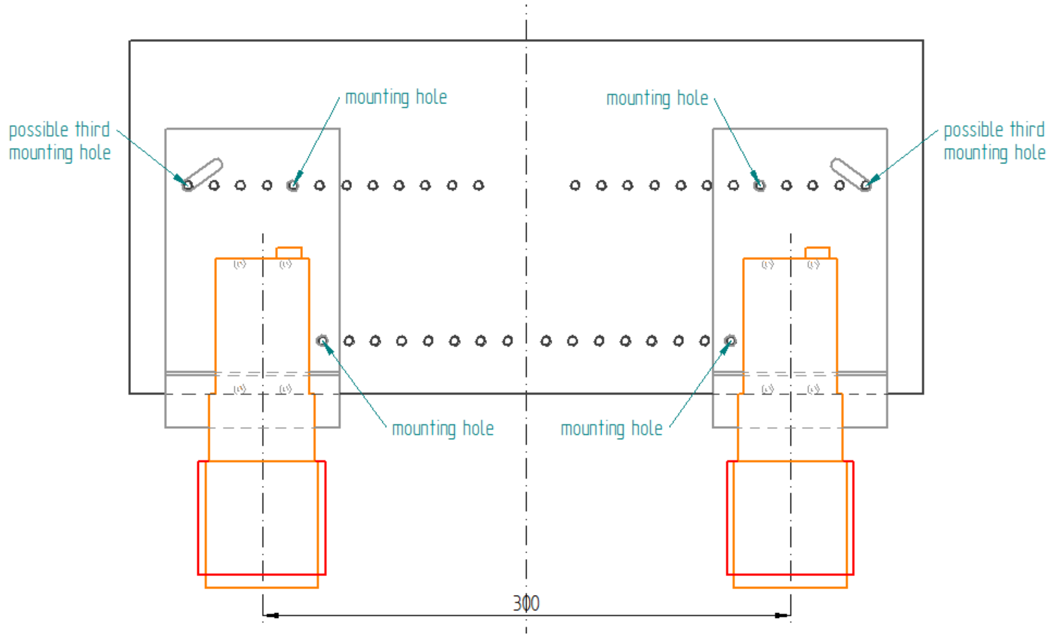

Figure 12: assembly axially parallel maximum distance (300 mm)

Thera are 7 possibilities to fix the camera plate on the mounting plate. With every step the camera axis gets 15 mm closer to the central axis of the mounting plate.

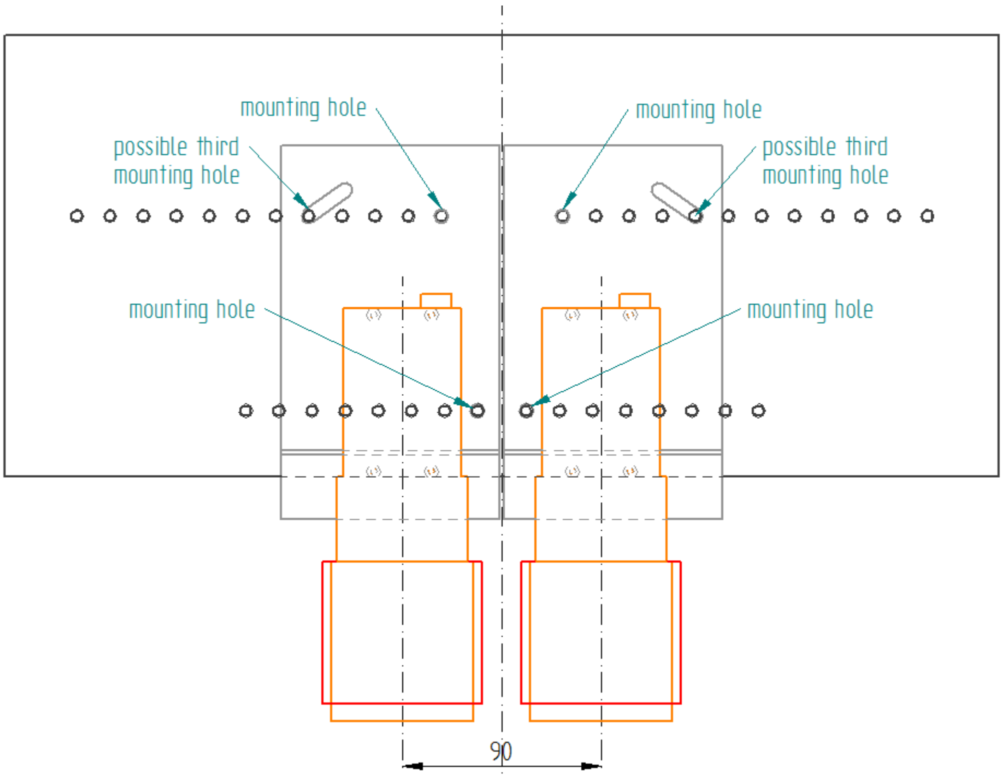

Figure 13: assembly axially parallel minimum distance (90 mm)

The minimum distance between the camera axes is 90 mm. The mounting holes are marked in the figure above. With two mounting holes it is guaranteed that the two cameras are axially parallel.

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4.4.3 Convergent mounting option

It is also possible to turn the camera up to 10° vertical reference. The center of rotation is marked in the figure below. With the help of the long hole in the camera plate it is possible to turn the camera axis freely adjustable up to 10°. At the one stop position of the long hole the camera axis is axially parallel.

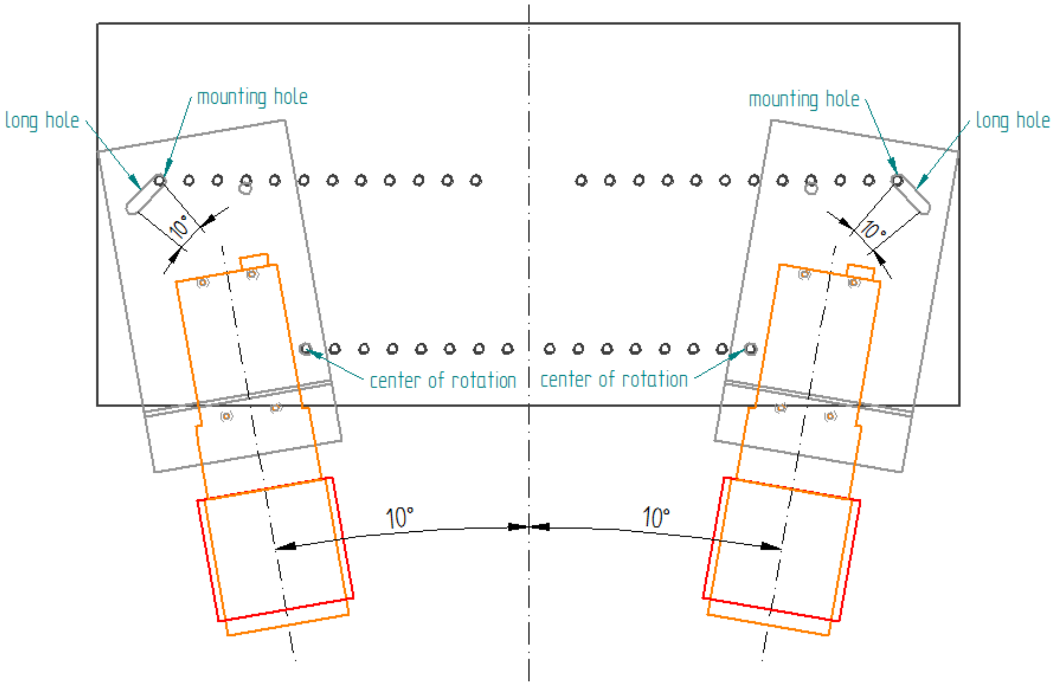


Figure 14: Assembly convergent maximum distance

It is also possible to mount the centre of rotation closer to the central axis of the mounting plate. With every step the centre of rotation gets 15 mm closer to the central axis of the mounting plate. In the figure below an example is shown.

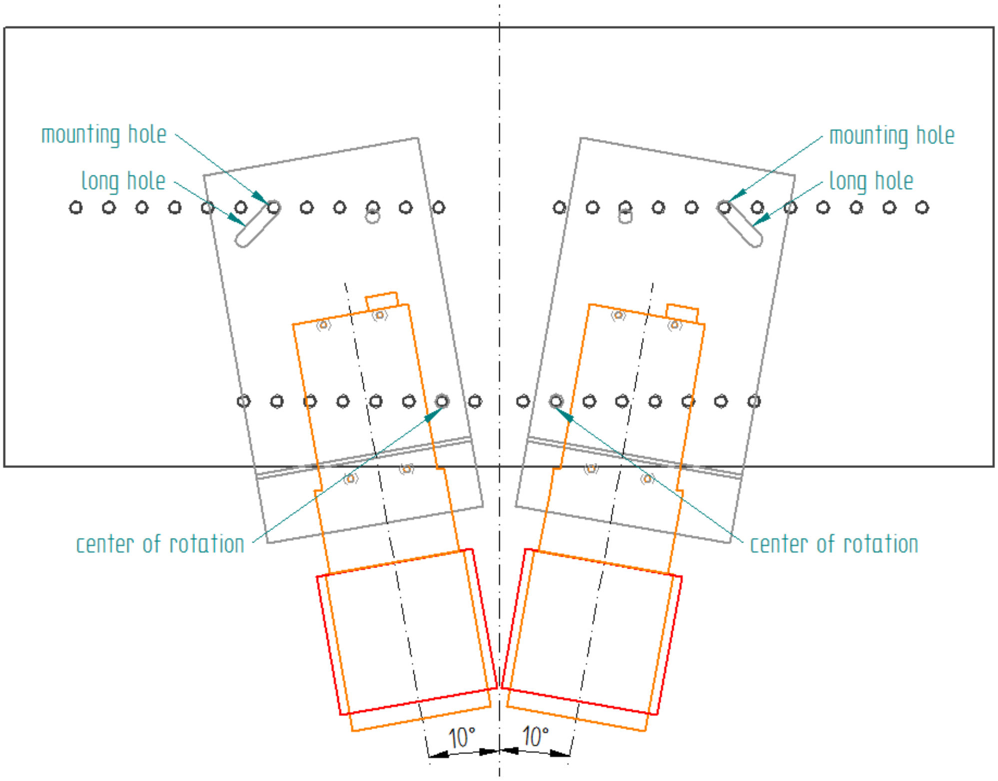


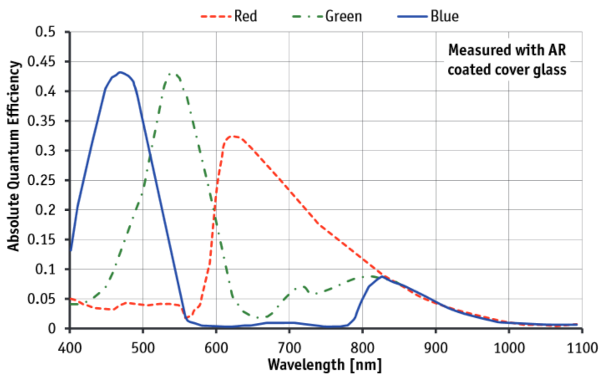
Figure 15: Assembly convergent minimum distance by maximum rotation

4.5 *Cameras*

Camera specification - Medium-Res. VIS Camera

The basic sensor in all Scanalyzer systems is the visible light sensor that can take images in the range visible light range.

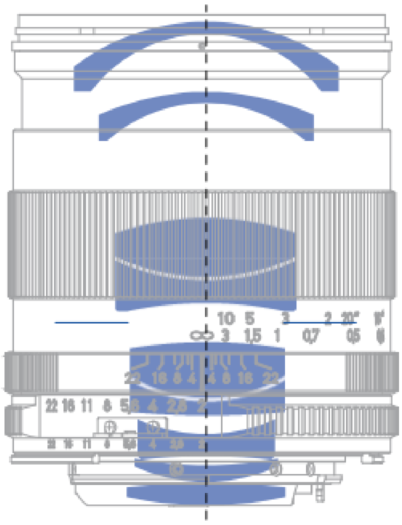
Specifications	
Interface	IEEE 802.3 1000baseT
Resolution	3296 x 2472
Sensor	Truesense KAI-08050
Sensor type	CCD Progressive
Sensor size	Type 4/3
Cell size	5.5 µm
Lens mount	F-Mount
A/D	14 bit
On-board FIFO	128 MB
Output	
Bit depth	14 (mono) - 12 (colour) bit
Mono modes	Mono8, Mono12, Mono12Packed, Mono14
Colour modes	YUV YUV411Packed, YUV422Packed
Colour modes	RGB RGB8Packed, BGR8Packed, RGBA8Packed, BGRA8Packed
Raw modes	BayerGR8, BayerGR12, BayerGR12Packed
General purpose inputs/outputs (GPIOs)	
TTL I/Os	1 input, 2 outputs
Opto-coupled I/Os	1 input, 2 outputs
Operating conditions/Dimensions	
Operating temperature	-20°C ... +60°C
Power requirements (DC)	PoE, or 7-25 VDC
Power consumption (12 V)	5.6 W@ VDC
Mass	314 g
Body Dimensions	
(L x W x H in mm)	121 x 59.7 x 59.7
Regulations	CE, FCC Class A, RoHS (2011/65/EU)



4.6 Lens system specification

4.6.1 Top view lens system

The object distance for the top cameras is about 1860 mm. The focal length is 35 mm. The technical specifications are shown in the figure below.



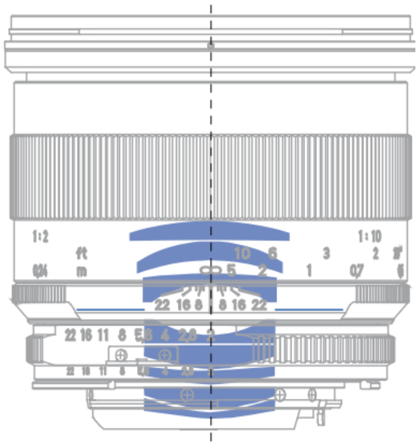
Brennweite/Focal length	35 mm
Blendenbereich/Aperture range	f/2– f/22
Linsen / Gruppen/Lens elements / Groups	9/7
Fokussierbereich/Focusing range	0,3 m (11.81″) – ∞
Arbeitsabstand/Free working distance	0,18 m (7.09″) – ∞
Bildfeld*/Angular field* (diag. / horiz. / vert.)	62° / 53° / 37°
Bildkreisdurchmesser/Diameter of image field	43 mm (1.69″)
Anlagemaß/Flange focal distance	ZF, ZF.2: 46,50 mm (1.83″) ZE: 44,00 mm (1.73″)
Objektfeld bei Naheinstellung* Coverage at close range (MOD)*	128 x 191 mm (5.04 x 7.52″)
Abbildungsmaßstab bei Naheinstellung Image ratio at MOD	1:5.3
Filterdurchmesser/Filter thread	M58 x 0.75
Lage der Eintrittspupille (vor der Bildebene) Entrance pupil position (in front of image plane)	86,0 mm (3.39″)
Drehwinkel des Fokussierrings (inf – MOD) Rotation angle of focusing ring (inf – MOD)	113°
Durchmesser max./Diameter max.	ZF, ZF.2: 64 mm (2.52″) ZE: 72,7 mm (2.86″)
Durchmesser des Fokussierrings Diameter of focusing ring	ZF, ZF.2: 63,4 mm (2.50″) ZE: 72,7 mm (2.86″)
Länge (ohne Objektivdeckel)/Length (without lens caps)	ZF, ZF.2: 72 mm (2.83″) ZE: 75 mm (2.95″)
Länge (mit Objektivdeckeln)/Length (with lens caps)	ZF, ZF.2: 97 mm (3.82″) ZE: 99 mm (3.90″)
Gewicht/Weight	ZF, ZF.2: 530 g (1.17 lbs) ZE: 570 g (1.26 lbs)

* bezugnehmend auf das 24x36mm Format/referring to 36 mm format

Figure 16: technical specifications of Distagon T 2/35 for top view imaging

4.6.2 Side view lens system

The object distance for the side looking cameras is about 3500 mm. The focal length is 50 mm. The technical specifications are shown in figure 16.



Brennweite/Focal length	50 mm
Blendenbereich/Aperture range	f/2 – f/22
Linsen / Gruppen/Lens elements / Groups	8/6
Fokussierbereich/Focusing range	0,24 m (9.45″) – ∞
Arbeitsabstand/Free working distance	0,10 m (3.94″) – ∞
Bildfeld*/Angular field* (diag. / horiz. / vert.)	45° / 38° / 26°
Bildkreisdurchmesser/Diameter of image field	43 mm (1.69″)
Anlagemaß/Flange focal distance	ZF, ZF.2: 46,50 mm (1.83″) ZE: 44,00 mm (1.73″)
Objektfeld bei Naheinstellung* Coverage at close range (MOD)*	48 x 72 mm (1.89 x 2.83″)
Abbildungsmaßstab bei Naheinstellung Image ratio at MOD	1:2
Filterdurchmesser/Filter thread	M67 x 0.75
Lage der Eintrittspupille (vor der Bildebene) Entrance pupil position (in front of image plane)	55,7 mm (2.19″)
Drehwinkel des Fokussierrings (inf – MOD) Rotation angle of focusing ring (inf – MOD)	303°
Durchmesser max./Diameter max.	ZF, ZF.2: 72 mm (2.83″) ZE: 75,4 mm (2.97″)
Durchmesser des Fokussierrings Diameter of focusing ring	ZF, ZF.2: 70,4 mm (2.77″) ZE: 75,4 mm (2.97″)
Länge (ohne Objektivdeckel)/Length (without lens caps)	ZF, ZF.2: 64 mm (2.52″) ZE: 67 mm (2.64″)
Länge (mit Objektivdeckeln)/Length (with lens caps)	ZF, ZF.2: 88 mm (3.64″) ZE: 91 mm (3.58″)
Gewicht/Weight	ZF, ZF.2: 500 g (1.10 lbs) ZE: 570 g (1.26 lbs)

* bezugnehmend auf das 24x36mm Format/referring to 36 mm format

Figure 17: Technical specifications of Makro-Planar T 2/50

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4.7 *Depth of field information and specification*

4.7.1 General

The depth of field depends on different influencing factors, for example: aperture, amount of light, object distance, focal length. Objectives were selected to provide a high depth of field for stereo imaging. The tables below do not show exactly the depth of field at the distances which will be used in the gantry system. But the depth of field can be interpolated. Due to the high availability of light small lenses apertures (high numbers) can be expected.

4.7.2 Top View

Schärfentiefe/Depth of Field (DOF)*

Engraved Distance	f/2		f/2.8		f/4		f/5.6		f/8		f/11		f/16		f/22	
Meter	from	to	from	to	from	to	from	to	from	to	from	to	from	to	from	to
infinity	22,60	∞	16,20	∞	14,40	∞	8,10	∞	5,70	∞	4,20	∞	2,90	∞	2,10	∞
3m	2,67	3,43	2,56	3,60	2,40	4,00	2,23	4,60	2,01	6,10	1,79	10,00	1,50	∞	1,30	∞
1,5m	1,42	1,59	1,39	1,63	1,34	1,70	1,29	1,80	1,22	1,97	1,14	2,20	1,03	2,90	0,93	4,50
1m	0,97	1,04	0,95	1,05	0,93	1,08	0,91	1,11	0,87	1,17	0,84	1,26	0,78	1,43	0,72	1,72
0,70m	0,68	0,72	0,68	0,72	0,67	0,73	0,66	0,75	0,64	0,77	0,62	0,81	0,59	0,87	0,56	0,95
0,50m	0,49	0,51	0,49	0,51	0,49	0,52	0,48	0,52	0,47	0,53	0,46	0,55	0,45	0,57	0,43	0,60
0,40m	0,40	0,40	0,39	0,41	0,39	0,41	0,39	0,41	0,38	0,42	0,38	0,42	0,37	0,44	0,36	0,45
0,35m	0,35	0,35	0,35	0,35	0,34	0,36	0,34	0,36	0,34	0,36	0,34	0,37	0,33	0,38	0,32	0,39
0,30m	0,30	0,30	0,30	0,30	0,30	0,30	0,30	0,31	0,29	0,31	0,29	0,31	0,29	0,32	0,28	0,32

* Schärfentiefetabelle für das 24x36mm Format, Zerstreuungskreis 0.029mm (D/1500), gerundet auf 0.01m
Depth-of-field table for sensor format 24x36mm, circle of confusion 0.029mm (D/1500), rounded to 0.01m

Figure 18: Depth of field Distagon T 2/35 mm objective. The plane of image will be at a distance of about 1.85 m. referring to the table using the engraved distance of 3 m at an aperture of F/8 will lead to a DOF from 2.01 m to 6.20 m which shows an example for the high DOF which is available.

4.7.3 Side View

Schärfentiefe/Depth of Field (DOF)*

Engraved Distance	f/2		f/2.8		f/4		f/5.6		f/8		f/11		f/16		f/22	
Meter	from	to	from	to	from	to	from	to	from	to	from	to	from	to	from	to
infinity	46,20	∞	33,10	∞	23,20	∞	16,60	∞	11,60	∞	8,50	∞	5,80	∞	4,30	∞
5m	4,53	5,60	4,36	5,90	4,14	6,30	3,87	7,10	3,53	8,60	3,18	11,90	2,70	32,00	2,30	∞
2m	1,92	2,08	1,89	2,12	1,85	2,17	1,80	2,25	1,73	2,38	1,64	2,57	1,52	3,00	1,39	3,60
1m	0,98	1,02	0,97	1,03	0,96	1,04	0,95	1,05	0,93	1,08	0,91	1,11	0,87	1,17	0,83	1,26
0,70m	0,69	0,71	0,69	0,71	0,68	0,72	0,68	0,72	0,67	0,74	0,66	0,75	0,64	0,77	0,62	0,81
0,50m	0,50	0,50	0,49	0,51	0,49	0,51	0,49	0,51	0,49	0,52	0,48	0,52	0,47	0,53	0,46	0,55
0,40m	0,40	0,40	0,40	0,40	0,40	0,40	0,39	0,41	0,39	0,41	0,39	0,41	0,38	0,42	0,38	0,43
0,35m	0,35	0,35	0,35	0,35	0,35	0,35	0,35	0,35	0,34	0,36	0,34	0,36	0,34	0,36	0,34	0,37
0,30m	0,30	0,30	0,30	0,30	0,30	0,30	0,30	0,30	0,30	0,30	0,30	0,31	0,29	0,31	0,29	0,31
0,27m	0,27	0,27	0,27	0,27	0,27	0,27	0,27	0,27	0,27	0,27	0,27	0,27	0,27	0,28	0,26	0,28
0,25m	0,25	0,25	0,25	0,25	0,25	0,25	0,25	0,25	0,25	0,25	0,25	0,25	0,25	0,25	0,25	0,25
0,24m	0,24	0,24	0,24	0,24	0,24	0,24	0,24	0,24	0,24	0,24	0,24	0,24	0,24	0,24	0,24	0,24

* Schärfentiefetabelle für das 24x36mm Format, Zerstreuungskreis 0.029mm (D/1500), gerundet auf 0.01m
Depth-of-field table for sensor format 24x36mm, circle of confusion 0.029mm (D/1500), rounded to 0.01m

Figure 19: Depth of field Makro-Planar T 2/50 mm. The plane of image will be at a distance of about 3.50 m. referring to the table using the engraved distance of 5 m at an aperture of F/8 will lead to a DOF from 3.53 m to 8.60 m which shows an example for the high DOF which is available.

5 Stereo camera system calibration

Calibration of the camera system either based on static calibration or autocalibrating approaches is in the full responsibility of the customer. This includes both software calibration and detail adjustment of the camera system.

LemnaTec will support the customer in setting up the system and guide the use of stereo imaging.

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