General Specifications

ProCam® and CamTest

Translation of the original General Specifications 04.11.2020

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1 Introduction

1.1 General information

TRIOPTICS GmbH has many years of experience in the development and manufacture of optical measuring and production systems.

The ProCam® and CamTest product families have emerged from the requirements for active alignment and series production of high-precision optical sensor systems and for testing the performance of camera modules.

This document contains basic information and specifications for measuring systems of the CamTest product series and production systems of the ProCam® product series from TRIOPTICS. The document is intended to support uniform understanding on measurement parameters and to describe the technical design and specified workflows over the life cycle of the systems.

NOTE

A list of the abbreviations used can be found in *List of abbreviations [▸ 59]*.

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1.2 ProCam – Active alignment, production and testing of camera modules and LiDAR systems

The production systems of the ProCam® product range are suitable for the production of camera modules and LiDAR systems.

Key features

- Active alignment in the sub-micrometer range
- Up to six degrees of freedom of movement (X, Y, Z, Rx, Ry, Rz)
- Real-time MTF measurement
- Final MTF testing or focus position check
- Suitable for infinite-finite and finite-finite conjugated samples
- Alignment of dual/stereo and triple cameras (on request)
- Easy to change between different camera types
- Automated process
- Optimized system for R&D assembly, small batch, and mass production

Sample process workflow

1. The sample (consisting of an objective lens and a sensor module) is manually inserted into the workpiece carrier at the loading and unloading position of the system. The automatic process for further processing is activated by the software
2. A VisionCamera is used to check whether the sensor has been inserted correctly.
3. A particle test is performed to check the sensor for any contamination.
4. If the particle test was successful, the sample is moved to the measurement and alignment chamber.
5. The gripper removes the lens from the sample holder and aligns it above the sensor.
6. If the alignment is basically possible, the sample is moved to the dispenser.
7. The dispenser moistens the sample with adhesive. A VisionCamera is used to check whether the adhesive bead is complete.
8. Then the sample is moved into the measuring and alignment chamber and aligned. The adhesive is cured by UV light.
9. The finished optics module is moved out of the measuring and alignment chamber back to the loading and unloading position. The automatic process is completed and the finished optics module can be removed.

1.3 CamTest module – Quality control for camera modules

The measuring systems of the CamTest product series enable measurements on installed camera modules, before and during running production processes and as a final quality check after production.

CamTest MTF – Determining the MTF

- Suitable for final quality control in the mass production of camera modules
- For testing camera modules with larger object distances
- Determine the MTF, LSF and ESF
- Use of collimators with fixed focal length, preset for infinite or finite object distances

CamTest Focus – Determining the Through Focus

- Suitable for testing fixed and autofocus modules
- Field of view of +/-90°.
- Determining the MTF, SFR, Through-Focus MTF, tilt/shift/rotation of the image plane
- Use of focusable collimators, variable object distance from finite to infinite in just one measurement setup

CamTest Chart – Determining the distortion

- Especially suitable for ADAS (Advanced Driver Assistance Systems)
- Suitable for calibrating cameras with strongly distorting optics
- Determining the camera viewing direction (relative to the mechanical reference of the camera)
- Determination of the position of the optical axis/center of the distortion
- Determining the LGD (Lens Geometric Distortion), camera boresight error, optical center, EFL of the camera and FOV.
- Setup with Test Chart at finite object distance
- With additional relay optics, it is possible to generate a virtual image of the chart as if from infinite distance; so a compact measurement setup replaces large test charts

CamTest Spectral – For measuring color rendering

- Suitable for measuring camera modules with up to 160° field of view
- Detection of pixel errors, FPN, color rendering, OECF, vignetting and dynamic range
- Setup with integrating sphere and finite object distance

2 Measuring parameters

2.1 MTF, SFR

MTF – Modulation Transfer Function

The MTF measurement is an important instrument for objectively assessing the imaging performance of an optical system. Especially for lenses, lens systems and objectives, the MTF is the quantitative evaluation criterion for image quality.

Since optical systems can never image reality with any errors, adjacent structures of different brightness appear blurred and can sometimes barely be recognized.

For the production and inspection of camera modules, a crosshair (cross reticle or edge reticle) is usually used as the object to be imaged. Mathematical methods make it possible to simultaneously measure different spatial frequencies. In addition, this approach allows the MTF to be measured simultaneously in two image directions, provided that a flat camera sensor is used.

In general, an illuminated test structure can be defined by:

- Spatial frequency (number of bright and dark areas per millimeter), and
- Contrast (difference between bright and dark areas in the image)

The MTF describes the ratio of image contrast to object contrast for different spatial frequencies.

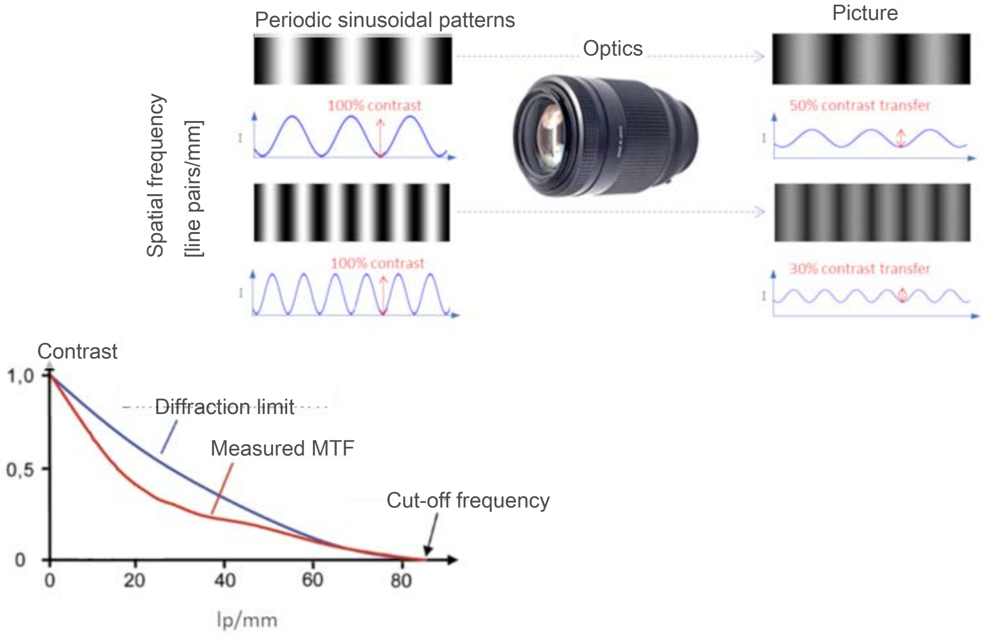

Fig. 1: MTF

In the classical approach, the object consists of sinusoidal brightness distributions with known contrast, the imaging of which is evaluated (*Fig. 1 [▸ 12]*).

Typically the MTF is normalized to unity at zero spatial frequency.

At low spatial frequencies, the MTF is close to 1 (or 100%) and generally drops off until it reaches zero as the spatial frequency increases. This is the limit of resolution for an optical system (what is known as the cut-off frequency).

Once the contrast value of zero is reached, the image of the corresponding spatial frequencies assumes a uniform shade of gray.

For the production and inspection of camera modules, a crosshair (cross reticle or edge reticle) is usually used as the object to be imaged. Mathematical methods make it possible to simultaneously measure different spatial frequencies. In addition, this approach allows the MTF to be measured simultaneously in two image directions, provided that a flat camera sensor is used.

SFR – Spatial Frequency Response

The SFR is a term used in particular for MTF measurement on camera modules. The terms MTF and SFR are usually used synonymously here.

The parameters MTF and SFR are based on the same measuring principle, but they differ in that they use different reticles. SFR is usually measured at edges, which is why, for example, a "slanted edge" reticle is used instead of the crosshairs (*Fig. 2 [▸ 13]*).

Fig. 2: Slanted edge reticle

The edge-based spatial frequency response (e-SFR) of an electronic still camera is determined by the camera image of the reticle shown above. The light-dark transition near the edge, which runs slightly obliquely through the image, is evaluated (*Fig. 3 [▸ 13]*).

This type of edge evaluation is also found in the corresponding ISO standards.

For optical systems: ISO15529- Optics and optical Instruments - Optical transfer function - Principles of modulation transfer function (MTF) of sampled imaging systems

For camera systems: ISO 12233 - Photography - Electronic still picture imaging - Resolution and spatial frequency responses

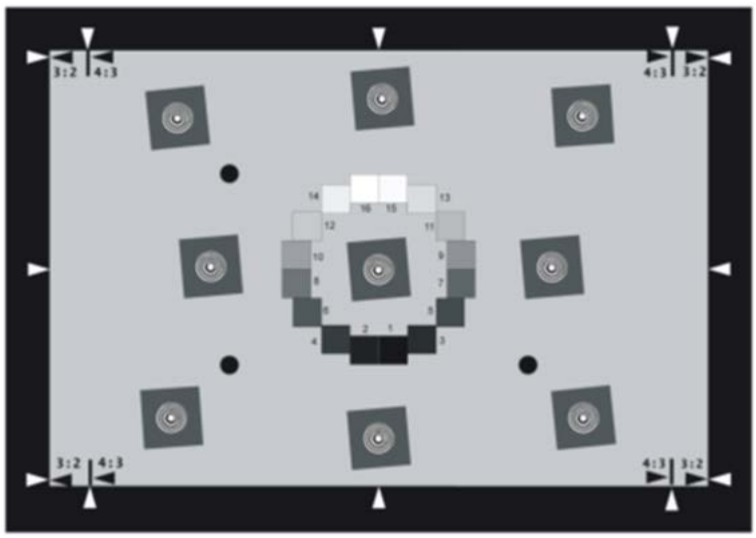

Fig. 3: Low contrast e-SFR chart

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2.2 Tilt, Defocus, DOF

Effects of misalignment

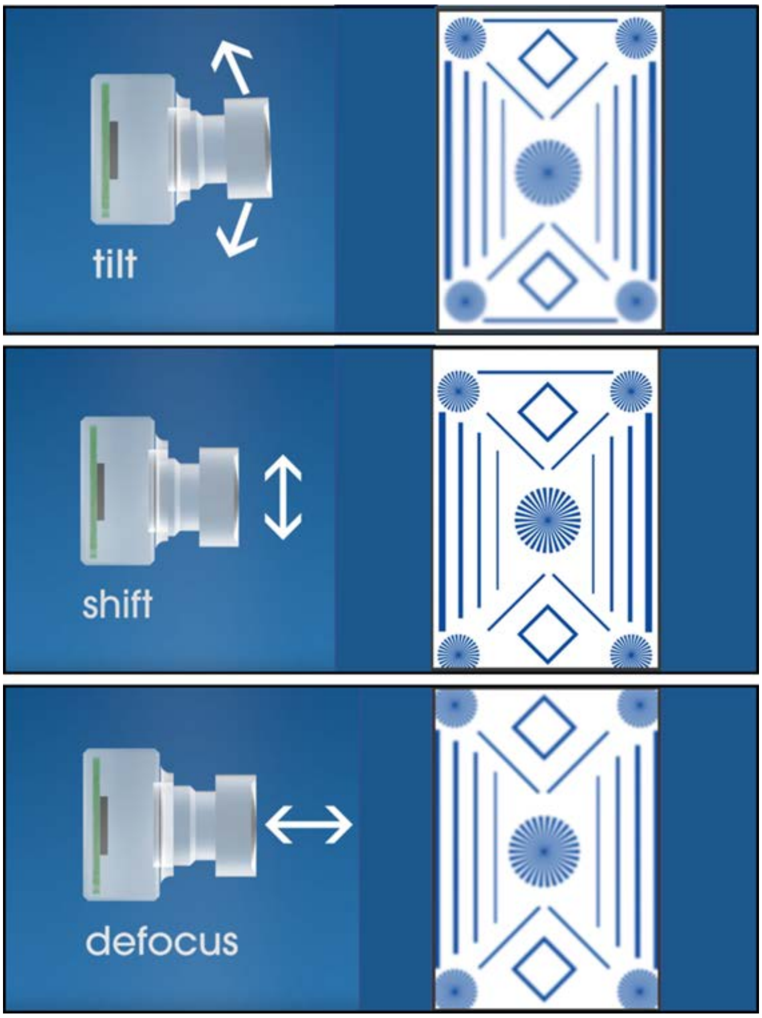

Fig. 4: Effects of misalignment

Misalignment corrected

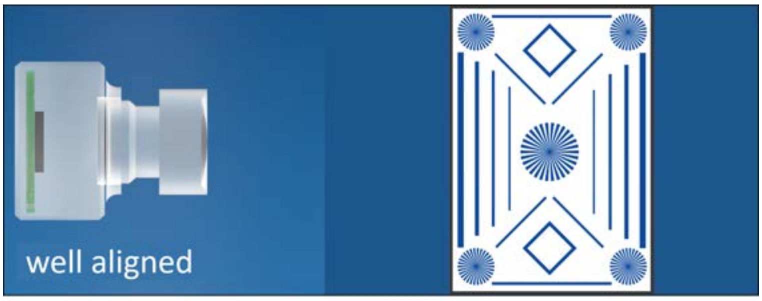

Fig. 5: Misalignment corrected

Tilt – Image plane tilt

The on-axis and off-axis best focus positions can be determined by a through focus scan. These positions can be used to fit a level. The image plane tilt is given by the normal vector of the fitted plane (*Fig. 6 [▸ 15]*).

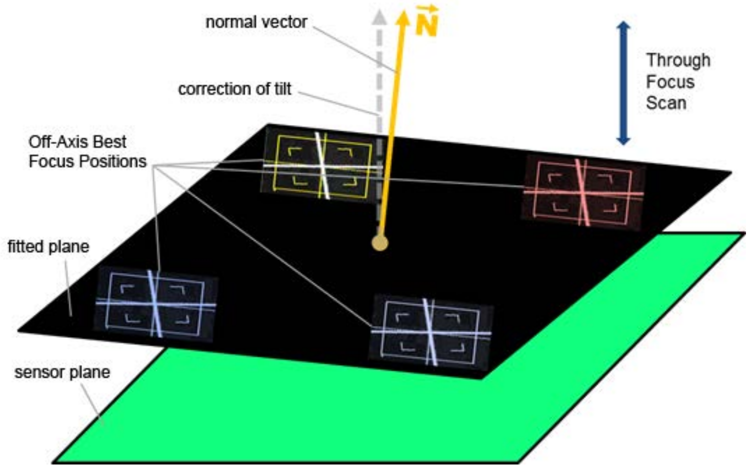

Fig. 6: Determination of the image plane tilt

The image plane tilt is specified either in polar angle (tilt angle) and azimuth angle (tilt orientation) or alternatively in tilt by x and tilt by y.

Defocus

The cameras that are usually measured and aligned with TRIOPTICS equipment, are focused on a certain object distance (for example 1 m, 10 m, infinity).

To check the focus, the position of the best image plane or the deviation from a target position is measured. This deviation is called "defocus" and is in the direction of the optical axis or parallel to it.

DOF – Depth of focus

The depth of focus is the area in front of and behind the image plane where the image appears sharp.

The depth of focus can be determined with a "Through Focus Scan" by defining a sufficiently sharp image via an MTF value range. The depth range in which correspondingly high MTF values were measured gives the depth of focus.

To illustrate this measurement parameter, two images with different depth of focus are shown in the figure below. The depth of focus is lower in the left-hand image than in the right-hand image (*Fig. 7 [▸ 16]*).

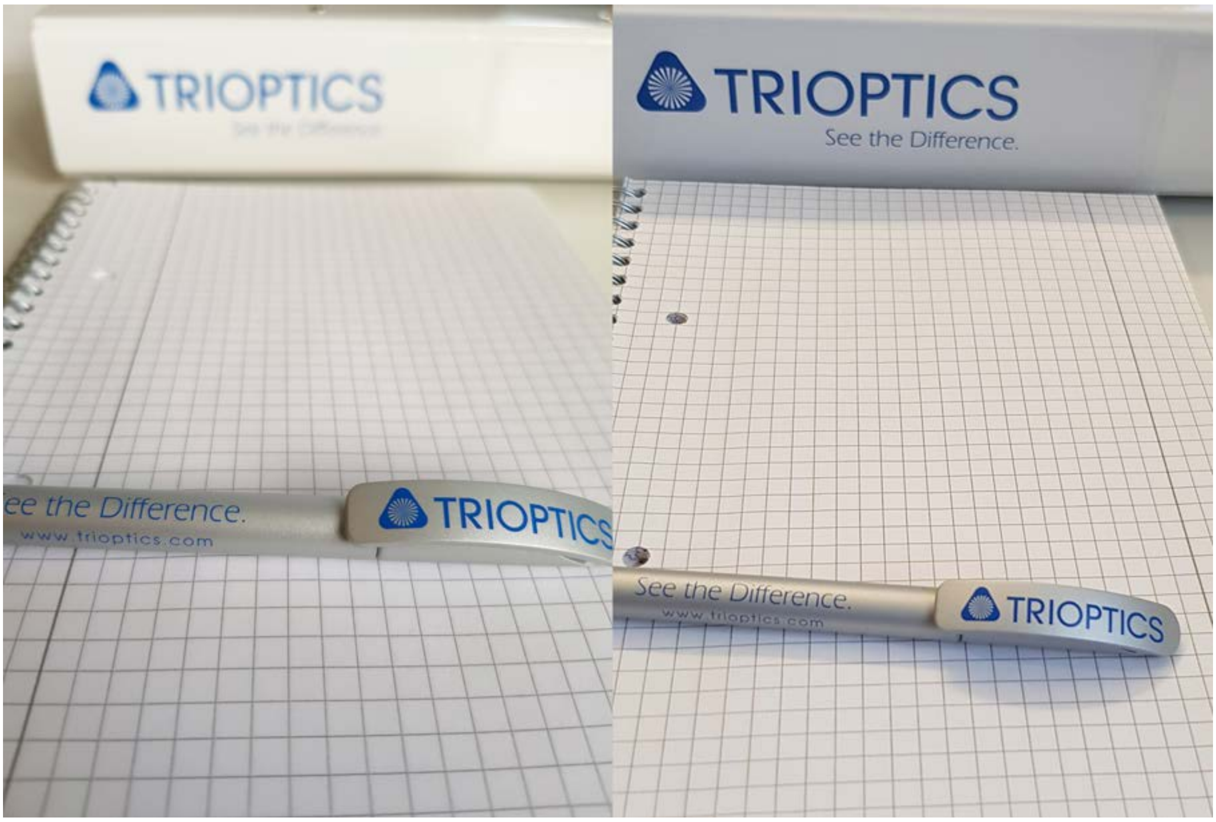

Fig. 7: Difference in the depth of focus between different apertures

2.3 Boresight shift, roll angle

Boresight shift – Camera viewing direction, X/Y shift

If the viewing direction of a camera is exactly perpendicular to a mechanical reference (e.g. the camera body), there is no image offset (*Fig. 8 [▸ 17]*, left).

If the viewing direction of the camera is shifted relative to the mechanical reference, there is an image offset. This offset is called "Boresight Shift" and can be measured in XY coordinates (*Fig. 8 [▸ 17]*, right).

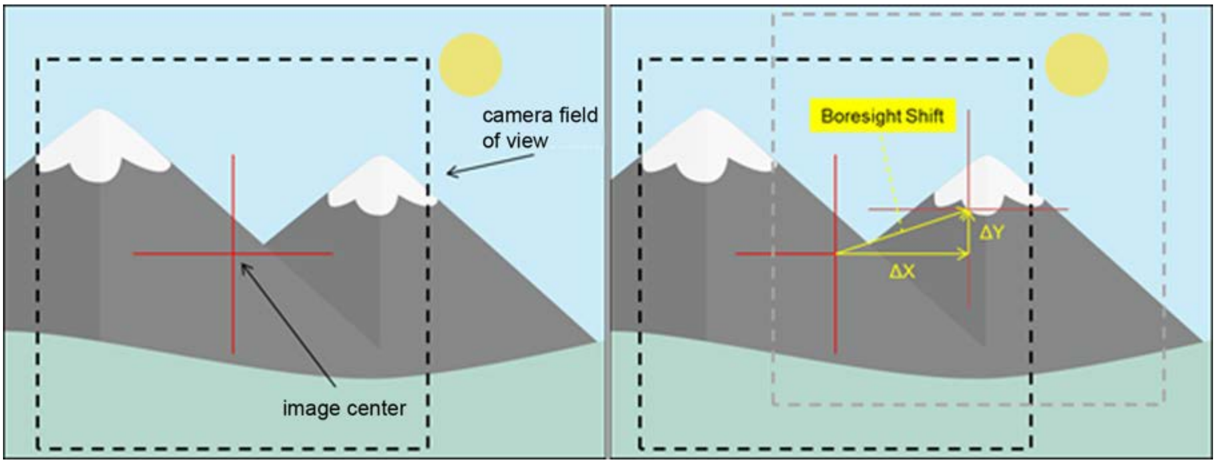

Fig. 8: Camera field of view changed due to boresight shift

The direction of view is aligned by shifting the lens or camera chip in XY so that the on-axis collimator cross is imaged in the center of the camera sensor.

Roll angle – Rotation of the image plane

When the image plane is rotated around the Z-axis, the angle is generally referred to as the roll angle (*Fig. 9 [▸ 17]*).

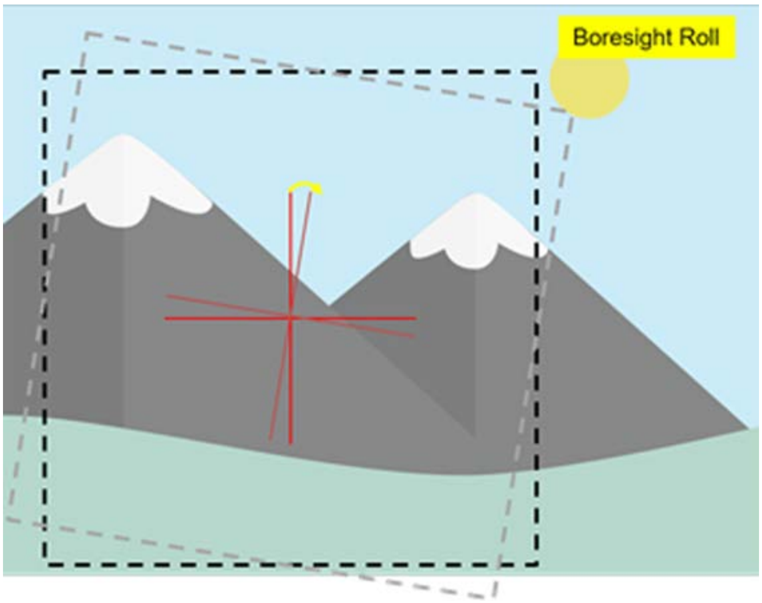

Fig. 9: Camera field of view changed due to roll angle

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2.4 Distortion, EFL

Distortion

The relative distortion is defined as the distance in the radial direction between the observed image point and the ideal image point. The relative distortion is expressed as a percentage of the ideal image height (theoretical distortion-free imaging).

TRIOPTICS distortion measurement is specified in ISO 9039:2008 and EBU Tech 3249. (The ISO standard deals only with radial distortion.)

- For a "normal" camera module TRIOPTICS uses the configuration infinite or finite object distance and finite image distance.
- General: In order to determine the distortion, conjugate value pairs of object and image-side coordinates must be measured.
- It is possible to use a distortion measurement to determine and correct the exact distortion values e.g. by using software (*Fig. 10 [▸ 18]*).

Fig. 10: Distortion

Distortion center (optical center)

If a rotationally symmetrical lens is assumed, the distortion center is the point of the symmetrical center of the distortion (*Fig. 11 [▸ 19]*).

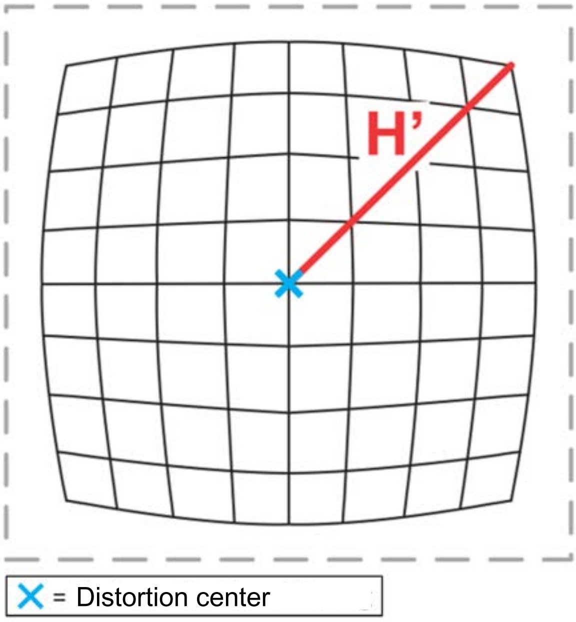

Fig. 11: Distortion center

Boresight center

The center of the center axis is the detected position of the center "bowtie target". If the system is well aligned to a mechanical reference of the sample, the "boresight center" is the viewing direction of the camera relative to its mechanical references.

TV Distortion (SMIA)

The TV distortion according to SMIA (Standard Mobile Imaging Architecture) is defined as:

$$\text{SMIA TV Distortion} = \frac{100 \times (A - B)}{B}$$

$$A = \frac{A_1 + A_2}{2}$$

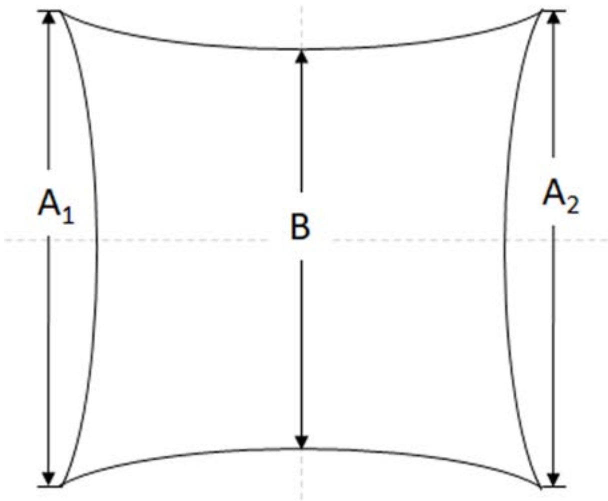

Fig. 12: SMIA distortion

TV distortion (EBU)

The TV distortion according to EBU (European Broadcasting Union) is defined as:

$$\text{EBU TV Distortion} = \frac{dA}{A}$$

Where A is the box height at the left-hand edge, to the right of the image. dA is the difference to the real edge image height.

EFL – Effective Focal Length

The effective focal length (EFL) is the distance from the focal points of the lens to the respective principal planes.

The EFL has a significant impact on the magnification of the image through the lens. Since the main planes are usually located at unknown locations within the lens, the EFL is determined indirectly via the magnification.

2.5 LGD

LGD – Lens Geometric Distortion

The geometric distortion of the lens is a relative distortion measurement that can be defined locally. While TV distortion is only defined at the edge of the picture (*Fig. 13 [▸ 21]*, *Fig. 14 [▸ 21]*), the LGD can be defined in any picture position.

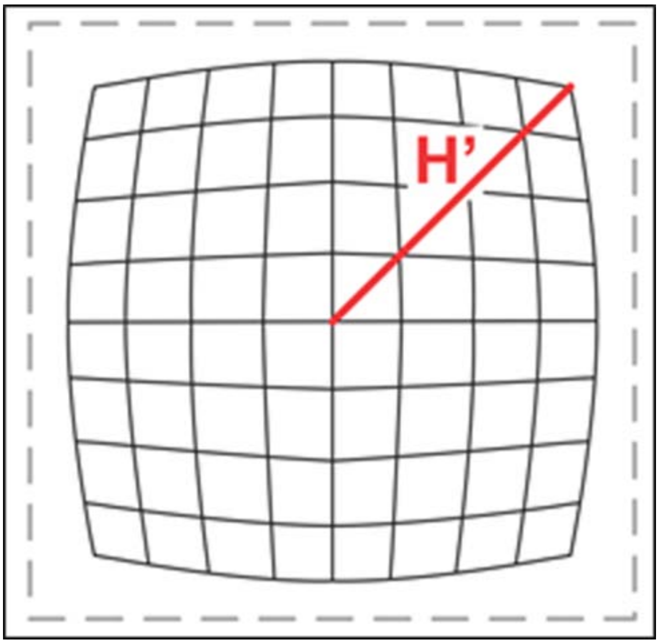

Fig. 13: Image height barrel distortion (TV distortion)

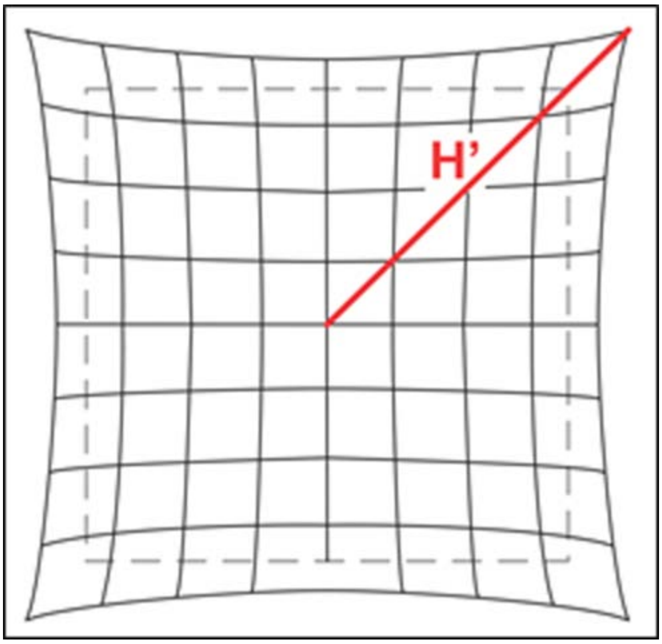

Fig. 14: Image height pincushion distortion (TV distortion)

It is assumed that the distortion near the optical center is zero. The detected target object grid is extended to the entire image and defines the target positions for each of the structures.

$$D = \frac{\Delta H}{H} \times 100 = \frac{H^* - H}{H} \times 100$$

Here H* is the distance of the image point from the image center.
H is the nominal distance of the image point from the image center based on the expanded grid.

The CamTest distortion module measures the lens geometric distortion (LGD) which is defined as follows:

$$D = \frac{R_d - R_u}{R_u} \times 100$$

Where Rd is the distorted radius to the distortion center and Ru is the undistorted radius (nominal value).The following linear equation is used to approximate the LGD, where two coefficients (a and b) are given to characterize the distortion behavior.

$$d = R_d - R_u = aR_u^3 + bR_u^5$$

becomes

$$\frac{R_d - R_u}{R_u} = aR_u^2 + bR_u^4$$

2.6 Defective pixels, particles

Homogeneous illumination of the camera module makes it possible to detect pixel errors (hot pixel, dead pixel) according to EMVA1288.

In addition, an analysis of visible particles in the camera module is made possible by using the CamTest Particle Test.

2.7 OECF, Dynamic Range, White Balance, SNR

OECF – Opto Electronic Conversion Function

SNR – Signal-to-noise ratio

The OECF measurement determines the ratio between the luminance of the light source and the digital intensity values output by the camera.

In the case of color cameras, this is carried out separately for all color channels (typically RGB). OECF measurement is based on the ISO 14524 standard and on EMVA1288.

In this measurement process, a light source with a defined spectrum is used and the luminance (cd/m^2) or alternatively the illuminance (lux) of the light source is gradually reduced from a saturated image to SNR = 1. The ratio of the input signal (luminance) in a central image area compared to the output signal (digital intensity value in the camera image) gives the OECF ().

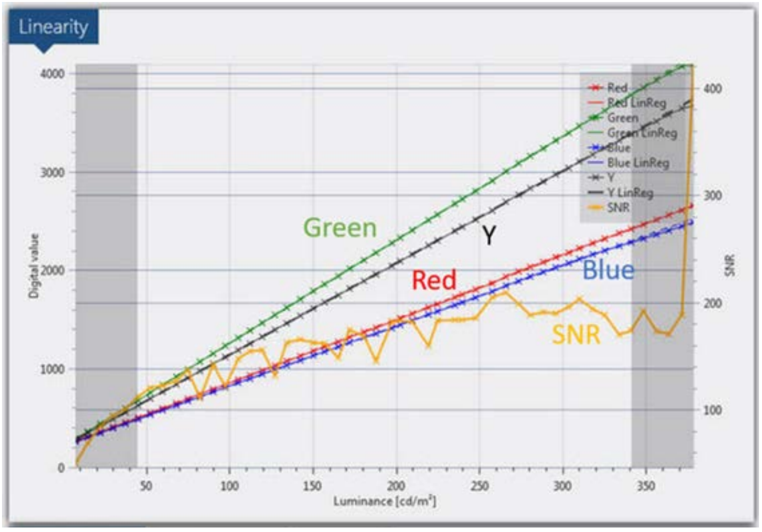

Fig. 15: OECF measurement with determination of the linearity error, the signal-to-noise ratio and the optimal white balance factor

The OECF is used to measure (non-) linearity according to EMVA1288, which is also required to determine the camera's MTF correctly. In addition, the OECF measurement serves to determine the signal-to-noise ratio from the mean value and the variance of digital brightness values as per ISO 15739.

For color cameras with linear OECF curves, factors for optimal white balance can be determined from the measured slopes of the various RGB OECF curves.

Dynamic range

The dynamic range describes the contrast of an image that the camera can reproduce. The dynamic range is determined by the OECF. To measure the dynamic range, the brightest point is selected in the illumination level, at which the camera reaches its maximum digital gray value. The darkest point is the illumination level at which the signal-to-noise level passes the value of 3. The dynamic range is the contrast between the lightest and the darkest point. ISO 15739 defines the dynamic range on the basis of a signal-to-noise ratio of 1.

White balance

White balance is the process of removing unrealistic color casts, so that objects which appear white in reality are rendered white in the image. When the automatic white balance works, the OECF curves of the color channels of red, green, blue of a camera sensor are superimposed (*OECF measurement with determination of the linearity error, the signal-to-noise ratio and the optimal white balance factor [23]*).

2

2.8 Relative Illumination, Shading

Relative illumination – Vignetting

Vignetting in an optical system is the gradual decrease of image brightness with increasing field angle. This is caused by several effects. The main influence is caused by geometrical relationships of the image, which is called natural vignetting or the $\cos^4$ or "cosine fourth" law. This includes the effect of the apparent limitation of the free aperture as a function of the field angle, which can be intensified by artificial vignetting. Further influencing variables are a field-angle-dependent transmission of the optics or an angle-dependent sensitivity of the sensor pixels.

Shading

An extended definition of vignetting according to ISO 17957 is called shading. In addition to vignetting, color inhomogeneity is also taken into account.

Color inhomogeneity produces a color change in relation to the image height, often caused by infrared filters in cameras, which can lead to angle-based spectral transmissions. To determine the shading based on ISO 17957, the image is divided into small sections in which the medium intensity is determined separately for each color channel. Assuming a radial, rotationally symmetrical characterization of the shading, the center and the averaged radial homogeneity curves are determined (*Fig. 16 [24]*, *Fig. 17 [25]*, *Fig. 18 [25]*).

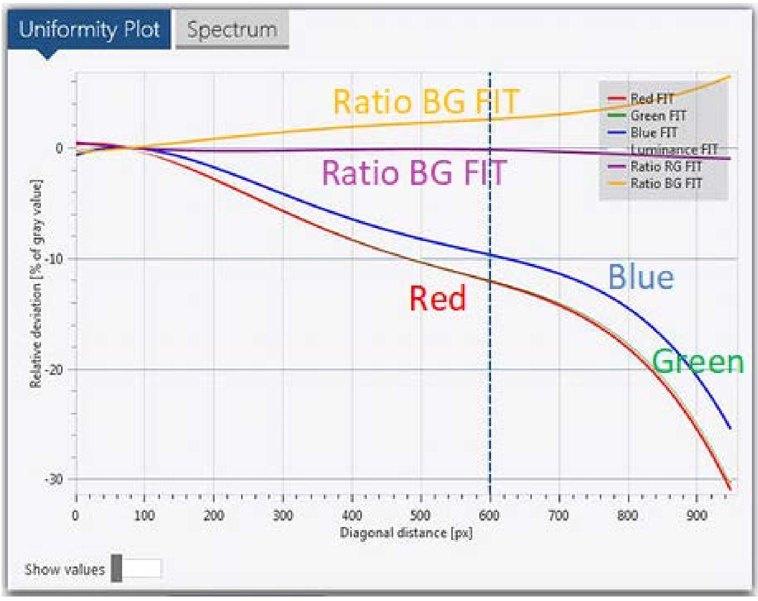

Fig. 16: Shading measurement showing relative illumination in relation to the radial image distances for each color channel

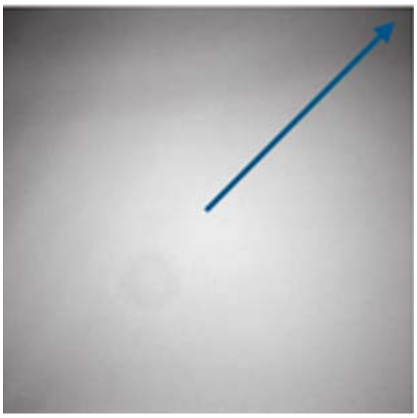

Fig. 17: Shading

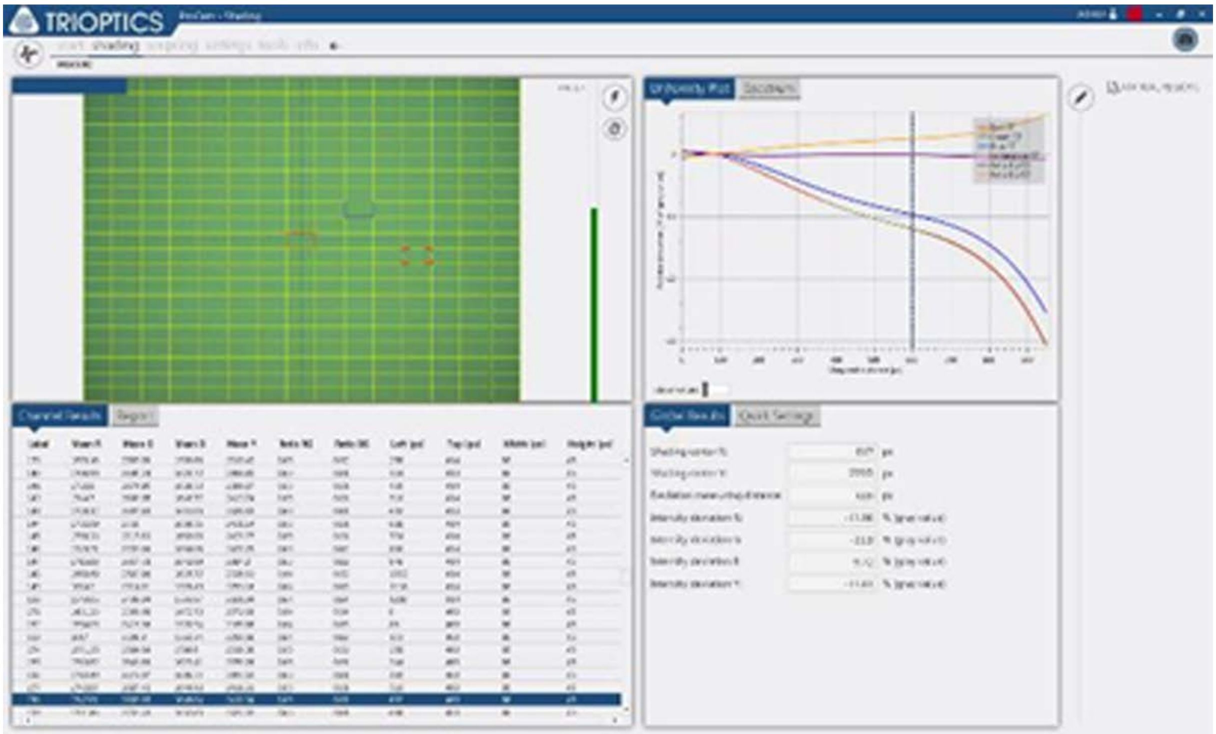

Fig. 18: Shading_3

2.9 Spectral sensitivity and color rendering

The CamTest spectral measurement makes it possible to determine the spectral sensitivity of color cameras. With the help of a "variable" narrowband light source, the color response of the camera is measured in a spectral range of 420 to 760 nm for each wavelength and this is used to calculate the curves for relative spectral sensitivity for each channel. The figure shows these measured spectral sensitivity curves (*Fig. 19* [*26*]).

In addition, color rendering measurements can be performed that are comparable to measurements using color test charts. These color rendering measurements have the advantage that the spectral measurement is more accurate and is not affected by illumination and aging effects of the test charts.

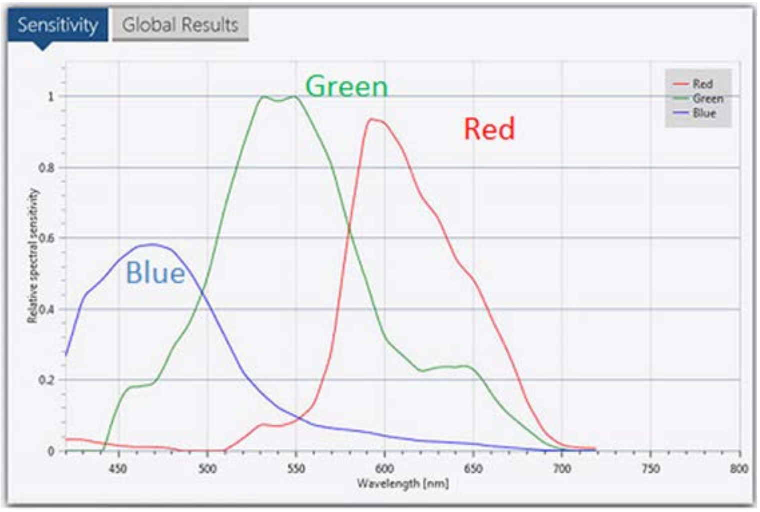

Fig. 19: Spectral measurement in which the sensitivity is determined for each color channel (RGB)

2.10 Camera alignment – From MTF measurement to active alignment

With camera modules, the correct focus position is an important factor for the image quality of the camera.

A correct focus position means that the image plane of the camera optics coincides with the sensor plane, whereby the deviation should be in the micrometer range.

For camera modules aligned in TRIOPTICS systems, the optics is usually a fix-focus optic (i.e. without the possibility of post-focusing), which is fixed and bonded in the correct position to the sensor. A 5-axis alignment of optics to sensor is possible (without rotation around the z-axis: roll angle) as well as a 6-axis alignment of sensor to optics or to mechanical reference.

Coordinate system of TRIOPTICS equipment

All measuring and production systems are based on a uniform coordinate system.

The Z-axis always corresponds to the direction of the optical axis of the sample optics.

The X-axis and Y-axis are defined relative to the gripper by default (*Fig. 20 [▸ 27]*).

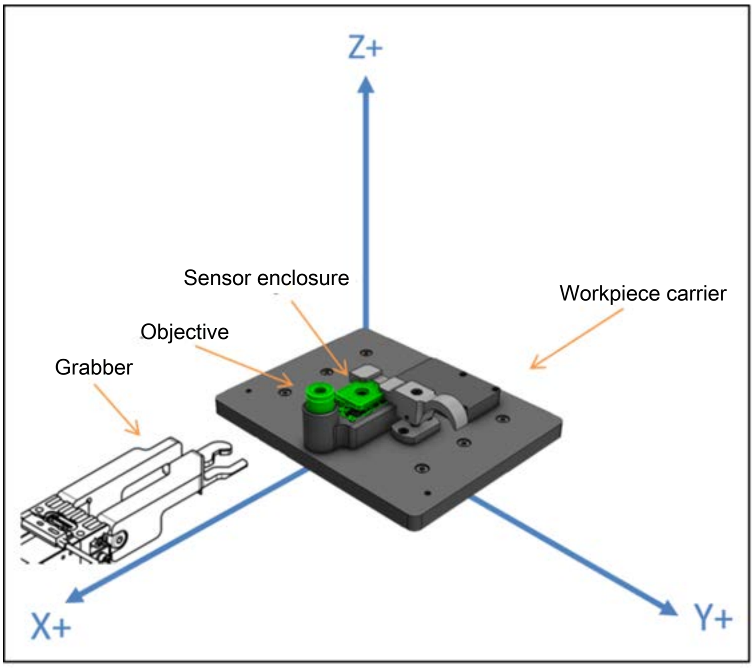

Fig. 20: Coordinate system of TRIOPTICS equipment

If desired, this definition can deviate, for example to adjust X and Y direction to the sensor orientation (*Fig. 21* *[**▸ 27**]*).

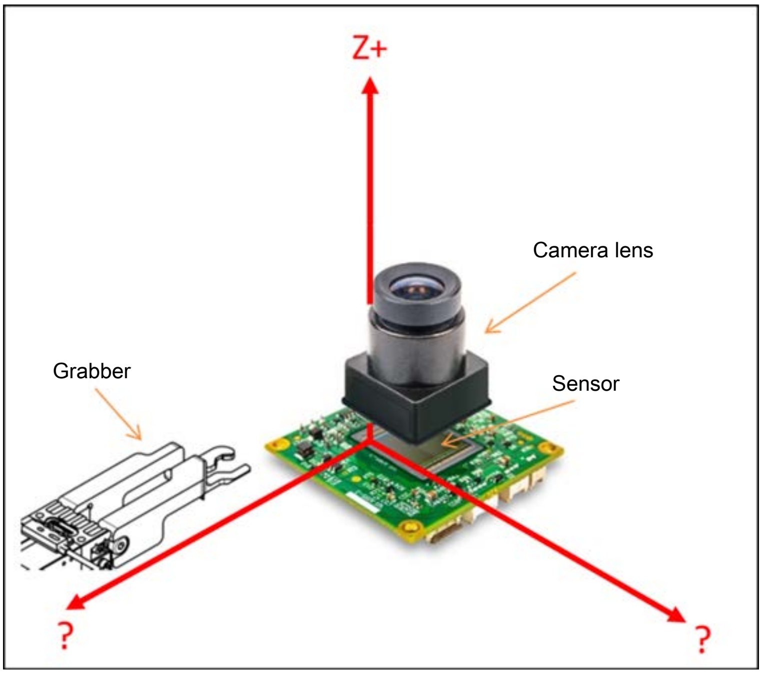

Fig. 21: Deviating sensor coordinate system

Terms used in the active alignment of camera modules

Through-Focus curves

The Through-Focus curves show an MTF value curve as a function of the focus. (*Fig. 22 [**▸ 28]*)

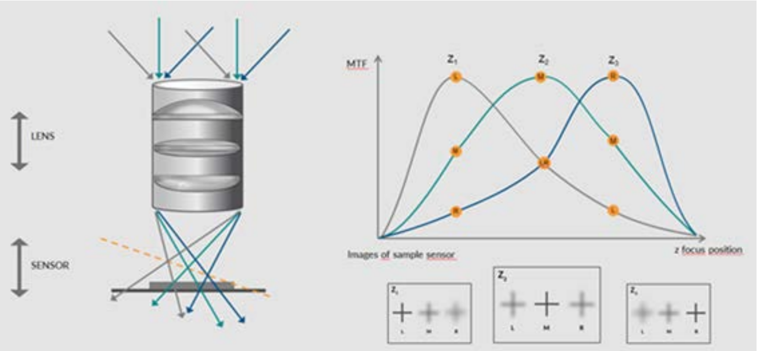

Fig. 22: Representation of the Through Focus curves at three different measuring positions

After a successful active alignment, all targets are simultaneously imaged on the sensor with the maximum possible sharpness. (*Fig. 23 [**▸ 28]*).

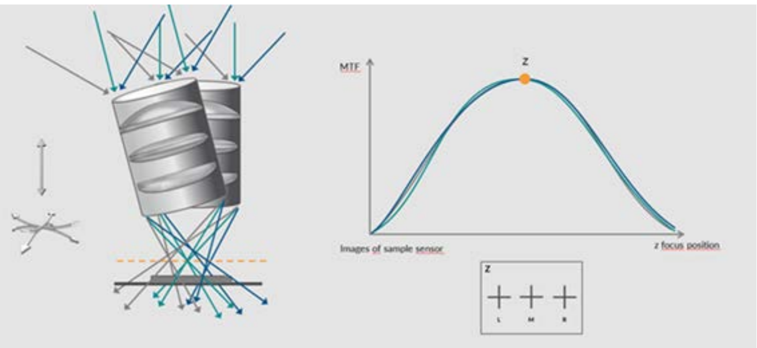

Fig. 23: Principle of alignment via Through Focus curves

Best Focus plane

The Best Focus plane is a plane for which the MTF values at the different measuring positions are optimized on average.

There are several possibilities for plane calculation and weighting, which can be defined in the software.

Influences on the alignment result

Environmental influences

Vibration and temperature in particular have a major influence on the alignment result.

Vibrations and shocks in particular can cause alignment to be impossible, because the through-focus curves are distorted.

TRIOPTICS offers the option of positioning the CamTest modules on damper elements. These can compensate for the usual building vibrations. Shocks (e.g. from robots, lifting equipment, etc.) in the immediate vicinity of the measuring chamber must be avoided. The systems should be installed in a stable, low-vibration environment. Robots, feed stages, feed upstrokes, etc. should be set up separately from the alignment chamber on a separate frame.

The second influence is temperature. Alignment in the micrometer range can be reproducibly guaranteed only for a small temperature range. The positioning devices and the target calibration are only stable in a small temperature range.

A temperature-controlled environment must therefore be ensured for the alignment systems.

Sample influences

The sample (camera module consisting of sensor and lens) itself can have an influence on the alignment result. Samples with poor imaging quality tend to be poorly aligned due to the low MTF measured values.

Too much mechanical tilt of the sample can lead to insufficient valid measured values being generated to start the alignment process.

Another requirement for the sample optics (lens) is that the effective focal length (EFL) and the flange focal length (FFL) do not vary too much. Dispersion of max. +/- 0.5% EFL should be aimed for here. The optical axis should not be tilted more than +/- 0.5° to the housing.

If possible, any image pre-processing (ISP, Image Sensor Processing) should be disabled for the sample sensors. Furthermore, a high signal-to-noise ratio is required in order to be able to align repeatably.

An unfavorable choice of the focus criterion or poor image quality of the sample can result in very wide through-focus curves, which have a negative impact on alignment accuracy.

A strong distortion interferes with the MTF edge evaluation, especially at the edge positions of the image field. Within the image area used, a relative distortion of 35% should not be exceeded.

3 Technical design

3.1 Cycle time, process time, units per hour

The output of production plants is usually expressed in maximum units per hour (UPH).

TRIOPTICS systems are specified with the pure process time, from the time the processing starts to the completion of a product or process. All other times such as setup time, loading and unloading time and maintenance time are excluded, as these depend on the respective production environment. If loading and unloading can take place within the process time during parallel processing, the cycle time corresponds to the process time.

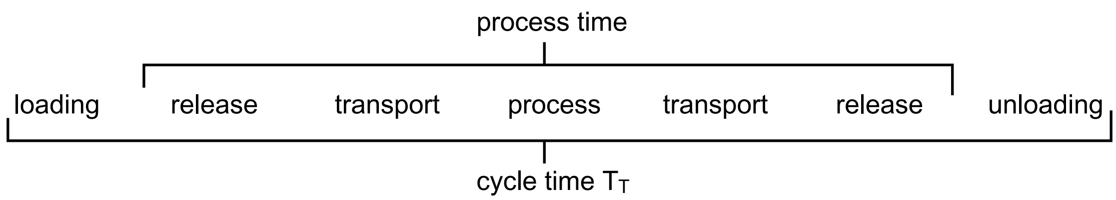

Fig. 24: Cycle time/process time sequential processing

3.2 Process technology

Dispenser

Before active alignment, adhesive is applied to a suitable surface in order to bond the sensor to the optics unit.

A defined adhesive structure is applied. The adhesive geometry can be closed or intermittent. It must be possible to apply the adhesive from one direction (above).

A 3-axis portal is used.

It is the customer's responsibility to select the adhesive. The type of adhesive must be defined as part of the specifications before the order is placed.

Vision

Before active alignment, the sample or the adhesive bead can be inspected by machine vision. Machine vision tasks must be verified by a feasibility study. Test criteria must be specified in advance and coordinated with TRIOPTICS. It must be possible to detect the objects being tested with high contrast. For this purpose, identical samples (same materials, same surface condition and finish) must be available.

The adhesive bead is inspected from the orthogonal direction to the adhesive surface using suitable 2D illumination.

Test criteria can be:

- Sample present
- Lens present
- XY offset of the workpiece
- Average adhesive bead thickness
- Minimum/maximum adhesive bead thickness
- Gaps in the adhesive bead
- XY offset of the adhesive bead
- Detection of bubbles in the adhesive

Implementation of the machine vision task for acceptance is restricted.

The machine vision task is optimized for small series with at least 100 different good/bad images in pre-series production.

Vision is optimized for large series with at least 500 different good/bad images in pre-series production.

The images must be provided by the customer. The distinction between good and bad images is made by the customer on the basis of the previously specified test criteria (see above).

UV Curing

After the active alignment, the adhesive is cured by UV light.

The result of the curing depends on the adhesive used and the intensity of the UV light.

3.3 Hardware

Industrial PC

Industrial PCs are tested by TRIOPTICS GmbH and delivered free of malware. Ultimately, it is the customer's responsibility to take protective measures to ensure that no malicious software can get onto the PCs after delivery.

3.4 Software

The proprietary software from TRIOPTICS in its current version is installed on the system by TRIOPTICS during commissioning. TRIOPTICS controls the functions for the commissioned project by means of scripts, so the software remains unchanged.

TRIOPTICS uses three password protected access levels:

- Superuser: exclusive access for TRIOPTICS Service
- Administrator: Supervisor level, set up by the customer.
- Operator: Operator level, set up by the customer.

The customer receives an unlimited and non-exclusive right of use for the installed software from TRIOPTICS. Each software license can be used on one computer at a time (dongle protection); backup copies can be made.

System control

TRIOPTICS systems have at least the following operating modes:

Automatic mode

Automatic mode is used for the production of parts.

Teaching mode

Teaching mode is intended for setup and maintenance work. No parts are produced when the system is in teaching mode.

For each individual process step, it is necessary to confirm whether the step should be executed or skipped.

3.5 Electrical technology

General scope of application

The delivered system complies with the directives, standards and regulations applicable in the EU at the time the machine was placed on the market. The following regulations are complied with in their latest version:

1. Machinery Directive 2006/42/EC
2. Low Voltage Directive 2014/35/EC
3. EMC Directive 2014/30/EC Electromagnetic compatibility
4. DIN EN 60204-1 Electrical equipment of machines
5. DIN EN ISO 12100-1 Safety of machinery
6. EN ISO 13849-1 Safety of machinery

Electrical documentation

Technical documentation is prepared for each system, which includes the following documents for electrical technology:

1. Electrical design documents (circuit diagram created with the CAE program EPLAN P8) in printed form and as PDF
2. A risk assessment is carried out for each system, but this is **not** part of the technical documentation.

Switch cabinet – General information

Switch cabinets and control panels in the systems are easily accessible for maintenance and service.

All switch cabinets and enclosures containing electrical equipment are permanently marked with the ISO 7010-W012 graphical symbol.

The interior of the switch cabinet is designed in such a way that the maximum permissible temperatures of the respective components are not exceeded.

The wiring of the systems corresponds to the circuit diagram.

Switch cabinet – Structure

Not all systems have a locked switch cabinet. Some of the electrical components are mounted on a base plate, which is built into the system and accessible through a door. This structure is also referred to below as the switch cabinet.

Wiring is carried out using plastic ducts and mounting plates.

A space reserve of at least 10% is provided on the mounting plates.

The heat development and heat sensitivity of the components are taken into account in the switch cabinet structure and, if necessary, an EMC and ESD-compliant arrangement is ensured.

A maximum of two conductors are connected to contactors and terminals.

All conductive individual and add-on parts of the cabinet are earthed. The attachment point of the protective conductor bears the protection symbol (earth symbol in a circle) according to DIN EN 61 140.

The voltage of the systems may be tapped before the main switch, e.g. to use the service socket even when the main switch is switched off or to safely shut down the control PCs even if no UPS is installed.

All single wires live even when the main switch is switched off are orange and have an "external voltage" label.

Selection of contactors and equipment

The contactors are selected such that their electrical and mechanical service life corresponds to the service life of the entire system.

All contactors and equipment are only operated within the limits specified by the manufacturer:

- Limit values for voltage and current
- Protection against vibrations, shock etc.
- Requirements in terms of temperature, cooling, installation position

Cables and wires

Cables and wires are designed according to the corresponding requirements for environment, temperature and flexibility.

Only flexible cables are used for the wiring.

The cross-section is designed according to the power of the connected loads.

Wire colors

Color	Symbol	Voltage	Function
green/yellow	PE		Protective earth
green/yellow			Equipotential bonding line
light blue	N		Neutral conductor
black		400/230 VAC	Main circuit
orange		AC/DC	External voltage
blue		24 VDC	Direct current control voltage
blue/white		0 VDC	Direct current control voltage

Labeling

All cables that run outside the switch cabinet are labeled with the corresponding equipment label at both ends.

Individual wires are not labeled.

All switch cabinet components, sensors, and plug-in connections are labeled and correspond to the wiring diagram.

Wiring diagram

The circuit diagram is created with EPLAN P8.

The circuit diagram is structured as follows:

- Cover sheet
- Feed-in data
- Cover sheet
- Table of contents
- Electrical circuit diagram
- Pneumatics circuit diagram

The electrical schematic is numbered consecutively and there are no duplicate page numbers even when subdivided into locations.

Electrical installation

General information

The equipotential bonding is carried out according to EN 60204-1. All metallic parts of a system are electrically connected to each other and the system earth. Equipotential bonding points are labeled with the protection symbol (earth symbol in a circle) according to DIN EN 61 140.

The lights in the systems and, if necessary, in the switch cabinet are controlled via the HMI.

Status lights - System status

The system status is visualized by a three-color signal lamp in green, amber, and blue.

-------- Signal lamp: Green ---------

Off: Automatic mode off

Flashing light: Automatic ready – System waiting for workpiece carrier or material

Continuous light: Automatic running – System is running trouble-free

-------- Signal lamp: Amber ---------

Off: Sufficient material for the process flow available.

Flashing light: Lack of material – System producing

Continuous light: Lack of material – System standstill

-------- Signal lamp: Blue ---------

Off: no fault

Flashing light: Fault – also with emergency stop pressed

Continuous light: Control off

System control

A programmable safety PLC from the company Pilz is used for the functional safety of the systems. Preferably the "Pilz PNOZ mB0" model is used.

Systems with few actuators are controlled by the proprietary TRIOPTICS software "ProCam".

Systems with a comparatively high number of actuators and sensors are controlled via a Beckhoff PLC.

The EtherCAT bus system is used for decentralized peripherals.

The customer receives an unlimited and non-exclusive right of use for the programs from TRIOPTICS. Each software license can be used on one computer at a time (dongle protection); backup copies can be made.

Control programs including source code for PLC or system control remain the intellectual property of TRIOPTICS and are not disclosed or transferred.

3.6 Pneumatics

- The system operator must provide the following compressed air quality according to ISO standard 8573.1 through the main compressed air supply:
  Compressed air supply according to ISO/DIS 8573-1, Class 3, filtration level 1
  Oil residue: 0.01 mg/m^2
  Free particles: 0.01 mm
  Residual moisture at -20°C: 0.88 g/m^3
  Compressed air connection: 6 mm compressed air hose
- The operating pressure in the network is min. 6.0 bar and max. 8.0 bar.
- All systems are checked for leaks prior to delivery.
- All pressure data refer to a positive pressure "P" above atmospheric pressure.
- All systems are equipped with a maintenance unit.
- The basic equipment is a sufficiently dimensioned filter regulator.
- The filter unit is equipped with at least one 40 µm filter.
- The pneumatic devices are installed in a service-friendly way, i.e. the devices are easily accessible for adjustment and replacement.
- The individual devices are marked with the same name as used in the circuit diagram.
- Care is taken to ensure that the connection points are installed tightly so that leakage air is reduced to a minimum.
- The pneumatic systems are planned and designed in such a way that operating personnel are not put in danger in the event of faults, e.g. sudden leakage or power failure.

3.7 ESD

The ESD standard DIN EN 61340-5-1/4-1/4-5 is complied with. The "ESD - BUCH" from GROTHUSEN Electronic Systems Vertriebs GmbH also serves as an important reference.

All surfaces, paints, and components are designed to be conductive in the direct vicinity of the sample. Common aluminum anodized coatings (e.g. surface matt-etched (E6), anodized and compacted, min. layer thickness 10 µm) are ESD-compatible. The direct vicinity includes all positions of the sample (in the system) and its surroundings up to 1 m away, which are not shielded by conductive materials.

The conductivity measurement criteria only apply to components on which circular surfaces of at least 20 cm^2 can be placed. Air pressure hoses, cable ties etc. are excluded.

Metallic parts must generally be earthed.

It must be possible to equip the work area for the system operator with an ESD conductive strip.

3.8 Camera interfaces

The following specifications can be considered as a reference. Further customer-specific sample specifications on request / after clarification.

Image sensor signal interface

- Analog: PAL/NTSC, CVBS (CCIR Standard) (preferred interface)
- Digital synchronous parallel / DVI 8 to 16 bit (BT.601 Standard) (preferred interface)
- MIPI CSI 2.0 1, 2 or 4 LVDS lanes: Image format RAW, YUV, RGB (preferred interface)
- LVDS-protected (e.g. for Sony)
- SPI
- HD-SDI
- Coaxial press
- FPD Link III Serializer/Deserializer

Image Sensor Control Interface

- SCCB/I^2C/TWI (preferred interface)
- SPI
- RS232/UART
- CAN

Sensor/camera module requirements

- Max. sensor clock 68 MHz (excluding MIPI)
- Sensor IO 0.9 ~ 3.6 V
- Mains voltage 0.9 ~ 24 V (typically 0.9 ~ 3.6 V)
- Max. image data rate 2.5 Gbit/s
- Must have the ability to set operation to manual exposure and gain setting.

The automatic exposure/gain function must be turned off.

Necessary documents for embedding the camera module in TRIOPTICS systems

- Electrical connection diagram and circuit diagram of the camera with mechanical dimensions and description of the connector types / contact field dimensions
- Block diagram of the electronic components used on board such as Image System Processing (ISP), SerDes (Serializer/Deserializer) including data sheets of all components related to the image signal
- If available: Additional documentation of the adapter board (schematic and functions)
- 3D/2D drawing/step file for exact dimensions of the camera module
- Documentation of signal names, values (voltage levels) and directions (I/O)
- Sensor specifications for connecting the sensor to the framegrabber: Data sheet of the image sensor, application note
- Registry table for sensor (and ISP) settings and description of the sensor control interface
- If necessary: Switch-on/switch-off sequence of the sensor (usually included in the data sheet)

(Preferred interface) means that implementation can be done using standard hardware and tested hardware. No special grabber developments required.

In case the customer takes over the camera integration or essential parts of it (e.g. the .dll) independently, TRIOPTICS cannot guarantee the function of the processes or the system.

3

3.9 Workpiece carrier

The workpiece carriers developed specifically for the customer consist of high-precision mechanical and electronic components which ensure the functionality (optical/mechanical reference and electrical contacting) according to the customer's specifications.

All mechanical, electrical and electronic components must be handled with extreme care and mechanical influences in sensitive areas must be avoided. Handling is only permitted by qualified personnel and in accordance with the operating instructions.

The workpiece carriers may only be used for the following intended use:

- Holding and contacting of test specimens or components
- Transport of samples/components in a TRIOPTICS system

Any other utilization is considered unintended use.

To ensure proper functioning of the system, only components purchased from TRIOPTICS may be used.

Intended use also includes compliance with the prescribed cleaning and maintenance intervals.

4 Conditions

4.1 General contractual conditions

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4.2 TRIOPTICS logo and colors

The TRIOPTICS logo (see figure) consists of the "Siemens star" and the lettering and must not be modified or removed from the equipment or components.

Fig. 25: TRIOPTICS logo

4.3 Installation conditions

- Flat and stable surface
- Floor load capacity according to system datasheet
- Installation site must comply with vibration class VC-C.
- Altitude: -50 m to +2000 m above sea level

4.4 Supplies

Power supply

- External power supply according to technical data of the respective system
- The cells of a complete system are each supplied with a separate cable from the distribution board.

Compressed air

- External compressed air supply according to technical data of the respective system

4.5 Operating conditions

- Ambient temperatures 20 to 25°C
- Relative humidity 40 to 65 %
- No condensing moisture, not even during breaks in operation
- Air conditioning measures must be taken if the ambient temperature are different.

Cleanroom capability

The systems are designed for a cleanroom class ISO 7 (ISO 14644).

4.6 Documentation required from the customer

TRIOPTICS requires the following information before starting a project:

- Relevant optical specifications and drawings of all parts/components, reference surfaces with tolerances
- Specification and drawings of electrical connections
- Adhesive specification (adhesive provided by customer)
- Datasheets and specifications of the sensor's image acquisition interfaces

4.7 Cooperation required from the customer

The following points are mandatory for the project to progress according to schedule:

- For the duration of the project (from assignment to FAT), a project manager with decision-making authority (single point of contact) is available to our project manager as a contact person.
- The final drawings of individual parts for all workpieces to be machined with the respective tolerances must be available within one week after the order being placed.
- At the time of design, construction, preliminary acceptance, commissioning, trial run and acceptance, workpieces of all kinds must be available in sufficient quantity in accordance with the applicable drawings and in the appropriate manufacturing quality.
- Fulfillment and compliance with official requirements; obtaining official approvals; payment of official fees.
- Provision of appropriate installation conditions (heating, lighting, sanitary facilities for our installation personnel, enclosed and clean building, floor ready for occupation)
- Free use of waste containers at the installation site (small waste)
- Sufficient access to the installation site, provision of equipment for the transport of components
- All parts and services which are necessary for the performance of the order and which are not expressly listed in the order
- For bulky goods that cannot be transported by our mechanics, the customer must provide suitable means of transport
- Necessary pneumatic connections to the interfaces defined by TRIOPTICS
- Electrical main supply line to the interfaces defined by TRIOPTICS

- Network cabling (if necessary) to the interfaces defined by TRIOPTICS
- Grounding of all equipment to eliminate the possibility of static charge
- Protection of the supply lines and connections to the interfaces
- Changes to existing buildings and all foundation and masonry work
- Fire safety equipment in general
- Supply and installation of safety equipment including sprinkler systems, fire doors, fire alarms
- All safety devices to guard against collision
- Safety railings, protective walls, etc. to protect the installation site or the area of the equipment, which are prescribed by the local safety authorities or internal company safety officers and not included in the scope of delivery
- Safety barriers that are not included in the scope of delivery must be installed at the beginning of our installation.
- Access to the facility, power supply and light from 7:00 to 24:00 (daily)

4.8 Provision of parts by the customer

Please use an RMA number (Return Material Authorization) to send any parts to TRIOPTICS. You can retrieve this number online.

1. Open `http://www.trioptics.com`.
2. Select `<Service & Contact><RMA form>`.

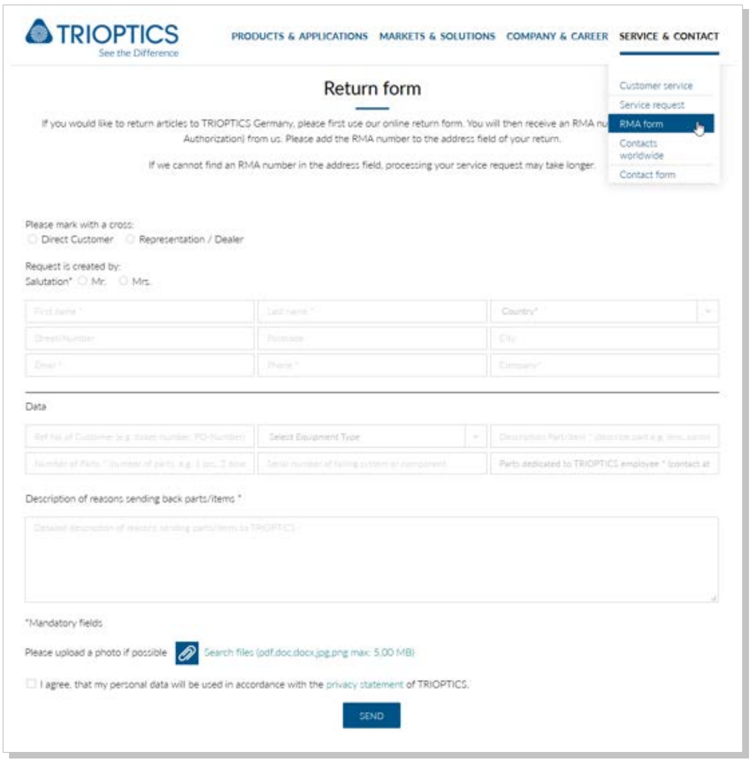

Fig. 26: Service RMA Form

3. Please mark if you are a direct customer or an agent/ dealer.
4. Select your salutation.
5. Fill in the respective fields.
6. All fields marked with an asterisk (*) are mandatory. If you do not know what to enter, fill in "None".
7. Describe the problem or error of the system in the field `Description of reasons for return`.
8. If necessary, select an attachment of the following file types: *.pdf, *.doc, *.docx, *.jpg, *.png.
   ⇨ The maximum size of the attachment is 5 MB.
9. Agree to the use of your personal data in accordance with the Privacy Policy.
10. Click `Submit`.
    ⇨ Your RMA number will be mailed to you.
11. State your address and the RMA number on the return package to TRIOPTICS.

NOTE

An RMA number is required to ensure your parts are assigned and processed quickly.

5 Documentation, documents provided

5.1 Technical drawings

- Overview drawing of the complete system as PDF
- Assembly drawings without dimensions as PDF

5.2 Risk assessment and conformity

- Risk assessment (on request and for inspection only)
- CE declaration of conformity

5.3 Operating instructions

- Operating instructions in German, 1 printout, 1x as PDF
- Translation of the original operating instructions in English, 1x printout, 1x as PDF

The operating instructions contain a maintenance plan and a spare parts list.

5.4 Supplier documentation

- Printout or PDF of the instructions for the supplier components

5.5 Pneumatics circuit diagram

- Pneumatic design documents in printed form and as PDF (circuit diagram created with the CAE program EPLAN P8)

5.6 Electrical circuit diagram

- Electrical design documents in printed form and as PDF (circuit diagram created with the CAE program EPLAN P8)

5.7 Other documents

- Calibration certificates of the measuring instruments used

6 Acceptances

The order is executed upon acceptance of the scope of delivery and services. The customer will be informed in writing of the readiness for acceptance.

Acceptance shall take place within 2 weeks. Acceptance cannot be refused due to insignificant defects.

The Site Acceptance Test, SAT for short, is the acceptance of a system at its place of installation directly at the customer's premises.

A Factory Acceptance Test (FAT) takes place at the TRIOPTICS' premises, upstream of the SAT.

The contents of the FAT and SAT are identical in content (see *Components of the acceptance protocol [▸ 48]*).

6.1 FAT

Before a TRIOPTICS system is shipped, a Factory Acceptance Test (FAT) must be carried out and accepted by the customer.

If the customer does not wish to participate in the FAT at TRIOPTICS' premises, TRIOPTICS employees will perform the FAT on its own and provide the FAT documentation to the customer afterwards.

After acceptance, the system will be delivered at the latest 2 weeks after notification of readiness for delivery.

6.2 SAT

The acceptance protocol is carried out in accordance with the conditions of the SAT document "Protocol of Acceptance".

If there are no significant defects, the system is considered accepted as of this point in time.

If the system consists of several independent stations or cells, each section is individually assessed and individually accepted (partial acceptance). Once the last section or cell is accepted, the entire system is considered accepted.

An incomplete scope of delivery or other open points are to be noted under Comments.

TRIOPTICS GmbH will rectify the open points within the jointly agreed time frame. The warranty starts for the accepted scopes. For open points, the warranty starts upon completion of the respective point.

The customer is obliged to create all prerequisites for conducting the SAT and, if necessary, to cooperate in necessary improvements.

If the acceptance procedure is interrupted or impeded for reasons beyond TRIOPTICS control, the final invoice will be issued at the latest 30 days after notification of readiness for acceptance.

The customer must meet all requirements for carrying out the acceptance procedure, for example the provision of a sufficient number of workpieces. The customer must ensure that the system works and that operating personnel are available free of charge.

6.3 Components of the acceptance protocol

The Protocols of Acceptance for FAT and for SAT are identical.

Ordering information

Order number (Trioptics order number)

Instruction and training

Names of all participants (trainers and participants)

Conditions for acceptance

- Installation and commissioning of the system
- Inspection of all delivered parts against the packing/order list
- Installation and commissioning
- Hardware and software functional test
- Explanation of the supplied documents and certificates

Operator training

- Quick start
- Setup procedures
- Practicing standard measurements
- Safety functions
- Regular maintenance

Absolute accuracy, repeatability

- Testing of absolute measuring accuracy and traceability on international standard test equipment
- Testing repeatability with regard to the specifications of the system

Appendices, comments

Example

Protocol of Acceptance
验收协议 / Abnahmeprotokoll

Product: 产品 / Produkt:	**Product name and version** S/N: Serial No.
Purchaser/customer: 采购方/客户 / Auftraggeber/ Endkunde:	**Customer name** Address 1 Address 2 Address 3 Country
Contractor: 承包商 / Auftragnehmer:	**TRIOPTICS GmbH** Strandbaddamm 6 22880 Wedel Germany

The protocol of acceptance is done according to the terms in this document. The delivered measurement system, the installation and the training are hereby accepted by the purchaser. In the case of missing parts and/or open points, those will be listed in remarks.
TRIOPTICS GmbH will take care of the open points according to the agreed schedule.

In case of discrepancies, the English version applies.

验收协议根据本文件的条款制定。交付的测量系统、安装和培训现已被采购者验收。当发生零件丢失和/或有未完成事项时，应在备注中列出这些情况。TRIOPTICS GmbH 将根据商定的时间表处理未完成事项。

如有不一致，以英文版为准。

Das Abnahmeprotokoll wird gemäß den Bedingungen dieses Dokumentes durchgeführt. Das gelieferte Mess-System, die Installation und das Training werden hiermit vom Auftraggeber akzeptiert. Ein nicht vollständiger Lieferumfang
oder andere nicht erfüllte Punkte des Kaufvertrages sind unter Bemerkungen festzuhalten. Die TRIOPTICS GmbH wird die offenen Punkte im vereinbarten Zeitrahmen beseitigen.

Bei Unstimmigkeiten gilt die englische Fassung.

place, date 地点、日期 / Ort, Datum	sign purchaser 签约采购方 / Unterschrift Auftraggeber
place, date 地点、日期 / Ort, Datum	sign contractor 签约承包商 / Unterschrift Auftragnehmer

TRIOPTICS GmbH • Strandbaddamm 6 • 22880 Wedel • Germany 1/4

Fig. 27: Protocol of Acceptance_Page_1

Protocol of Acceptance
验收协议 / Abnahmeprotokoll

TRIOPTICS

Order Information
订单信息 / Informationen zur Bestellung

Trioptics Order Number / 订单号 / Auftragsnummer

Instruction and Training: Participants
指导和培训：参加者 / Unterweisung und Training: Teilnehmer

Training performed by / 培训执行者 / Name des Trainers	
Name of the trained person / 受训人员的姓名 / Name des Teilnehmers	Name of the trained person / 受训人员的姓名 / Name des Teilnehmers
Name of the trained person / 受训人员的姓名 / Name des Teilnehmers	Name of the trained person / 受训人员的姓名 / Name des Teilnehmers
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Name of the trained person / 受训人员的姓名 / Name des Teilnehmers	Name of the trained person / 受训人员的姓名 / Name des Teilnehmers

Terms of acceptance
验收条款 / Bedingungen für die Abnahme

Setup of measurement system / 测量系统的设置 / Aufbau und Inbetriebnahme des Mess-Systems		
Remarks / 备注 / Bemerkungen:		accepted / 已验收 / akzeptiert
Preliminary tests (10–15 min) / **初步测试（**10–15 **分钟）/ Vorprüfung**		
1	Explanation of the provided documents and certificates / 所提供的文件和证书的解释 / Erklärung der mitgelieferten Dokumente und Zertifikate	
2	Check of completeness according to packing list / 根据装箱单检查设备的完整性 / Vollständigkeit der Komponente entsprechend Lieferschein	
3	Check of completeness of spare parts and manuals / 检查备件和手册的完整性 / Vollständigkeit der Ersatzteile und Handbücher	

Nur zu internen Zwecken: Nach der Installation und Inbetriebnahme ist das ausgefüllte und unterzeichnete Dokument zu scannen, die Dateibezeichnung des Scans zu ändern (Auftragsnr. PoAyyyymmdd) und im Geräteordner des Kundenauftrags abzulegen. Das ORIGINAL ist an die Auftragsabwicklung (Export) weiterzuleiten.

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Fig. 28: Protocol of Acceptance_Page_2

Protocol of Acceptance
验收协议 / Abnahmeprotokoll

TRIOPTICS

Visual inspection (10–15 min) / **目检（10–15 分钟）/ Sichtkontrolle**	
4	Check on external damages from transport and assembly / 检查是否有运输和装配造成的外部损坏 / Äußere Kontrolle auf Transport- und Montageschäden
5	Check on external contamination / 检查是否有外部脏污 / Äußere Kontrolle auf Verschmutzung
6	Check on external labels and CE / 检查外部标签和 CE / Äußere Kontrolle der Beschilderung und CE
7	Mobility of all moveable parts / 所有可动件的移动性（门、门折页、扣锁等）/ Gängigkeit aller beweglichen Teile (Türen, Steckbleche, Verschlüsse, etc)
8	Check on internal damages from transport and assembly / 检查是否有运输和装配造成的内部损坏 / Innere Kontrolle auf Transport- und Montageschäden
9	Check on internal contamination / 检查是否有内部脏污 / Innere Kontrolle auf Verschmutzung
10	Check on internal labels of components, electrical grounding, warnings / 检查组件、电气接地和警告的内部标签 / Innere Kontrolle der Beschilderung der Komponenten, Erdung, Warnung
Start-up of system & safety check (20–30 min) / **系统的启动 & 安全检查（20–30 分钟）/ Mess-System in Betrieb nehmen & Sicherheitscheck** (20–30 min)	
11	Check of power supplies and earth bolt if applicable / 适当时检查电源和接地销 / Einspeisungen eingeführt ggf. Anschluss Erdbolzen prüfen
12	Power-up of system as described in the manual / 按手册中所述接通系统的电源 / Gerät wie in Bedienungsanleitung einschalten
13	Check of safety functions: · Activate Emergency-Stop to stop travel motions · Release Emergency-Stop, press acknowledgement button to restart the system 检查安全功能: · 激活紧急停止时，系统是否急停 · 释放紧急停止时，按确认按钮系统是否重新启动 Sicherheitssysteme testen: · Not-Aus betätigen, Fahrbewegungen werden gestoppt · Not-Aus entriegeln, Quittierung betätigen, um Gerät zu starten
14	Check of acoustical and optical notification system / 检查声学和光学通知系统 / Akustische und optische Meldesysteme prüfen
15	Power-down, system is set to standby / 切断电源，系统设置为待机 / Gerät ausschalten, Gerät geht in Standby

Remarks / 备注 / Bemerkungen:	To be done until / 待完成操作 / zu erledigen bis:

Nur zu internen Zwecken: Nach der Installation und Inbetriebnahme ist das ausgefüllte und unterzeichnete Dokument zu scannen, die Dateibezeichnung des Scans zu ändern (Auftragsnr. PoAyyyymmdd) und im Geräteordner des Kundenauftrags abzulegen. Das ORIGINAL ist an die Auftragsabwicklung (Export) weiterzuleiten.

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Fig. 29: Protocol of Acceptance_Page_3

Protocol of Acceptance
验收协议 / Abnahmeprotokoll

TRIOPTICS

Operator training / 操作人员培训 / Anwendertraining	
Measurement basics of delivered measurement system; quick-start; alignment procedures; hard- and software training; maintenance; practice of standard measurements, safety instructions / 交付的测量系统的测量基础知识；快速启动；校准步骤；软硬件培训；维护，标准测量的做法，安全功能 / Grundlagen der Messtechnik des gelieferten Mess-Systems; Schnellstart; Einrichtungsprozeduren; Hard- und Softwaretraining; Pflege und Wartungstätigkeiten, Übung von Standard-Messungen, Sicherheitsfunktionen	accepted / 已验收 / akzeptiert
Remarks / 备注 / Bemerkungen:	To be done until / 待完成操作 / zu erledigen bis:

Absolute accuracy, repeatability / 绝对准确性、可重复性 / Absolute Genauigkeit, Wiederholgenauigkeit	
Check of Absolute accuracy and traceability to international standards; check of repeatability based on the measurement system specifications / 检查基于国际标准的绝对准确性和可追溯性；基于测量系统规范检查可重复性 / Prüfung der Absoluten Messgenauigkeit und Rückführbarkeit auf internationale Standardprüfmittel; Prüfung der Wiederholgenauigkeit bezüglich der Spezifikationen des Mess-Systems	accepted / 已验收 / akzeptiert
Remarks / 备注 / Bemerkungen:	To be done until / 待完成操作 / zu erledigen bis:

Attachments / 附件 / Anhänge		accepted / 已验收 / akzeptiert
Remarks / 备注 / Bemerkungen:		To be done until / 待完成操作 / zu erledigen bis:

Nur zu internen Zwecken: Nach der Installation und Inbetriebnahme ist das ausgefüllte und unterzeichnete Dokument zu scannen, die Dateibezeichnung des Scans zu ändern (Auftragsnr. PoAyyyymmdd) und im Geräteordner des Kundenauftrags abzulegen. Das ORIGINAL ist an die Auftragsabwicklung (Export) weiterzuleiten.

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Fig. 30: Protocol of Acceptance_Page_4

6.4 Machine capability / Process capability

Machine capability indicates the stability and reproducibility of a production step on a machine/system. It enables a statement about the extent to which rejects and reworking are to be expected when operating this system. The machine capability is closely connected to the process capability indices Cp and CpK of a production process.

The machine capability of the system depends on the quality of the samples and the materials used. If the quality of the reference surfaces, the mounting of the sample, the reproducibility of the sensors, optics, etc. are adequate, typical process capabilities of Cpk = 1.33 are achieved in a temperature range of ±2°C.

Comment

Typically the Modulation Transfer Function (MTF) is normalized to one at zero spatial frequency (non-normally distributed measured values). The closer the MTF is to 1, the higher the resolution of the system (see section *MTF, SFR [▸ 11]*). A process capability test determines the deviation of a sample from a target value. An upper and a lower tolerance limit are defined (e.g. +/-0.04). The closer the values are to the target value, the higher the calculated CpK.

Example

Assuming the target value for an MTF measurement is 0.5 and the tolerance is +/- 0.04. Then a value of 0.7 would have a negative effect on the process capability (tolerance in one direction exceeded), although a higher MTF means a better resolution.

7 Transport

7.1 Execution and requirements

- Systems must not be stored outdoors during transport to/from the place of use.
- The relative humidity must be between 40 - 65%.
- The temperature must not exceed or fall below the -10 to +60°C limit values.
- Transport monitoring must be provided for inclination, shock, temperature, humidity. (see https://transport-control.de/)

Fig. 31: Transport

- The system stands on adjustable feet.
- The system can be used with a forklift (not on all sides).
- The system is transported in a suitable transport box.
- The system is securely fastened in the transport box

7.2 Limits of the scope of delivery

Deliveries from TRIOPTICS do **not** include:

- Cranes and lifts for the transport of parts to and at the place of installation (except those mentioned in the offer)
- Calibration equipment or master parts (except those mentioned in the offer)
- Connection to external devices (except the devices mentioned in the offer)
- All components that are not explicitly mentioned in the offer

8 Installation/training at the customer's premises

8.1 Assembly/Commissioning

We expect unhindered delivery and commissioning of the system. In case of delays that are not the fault of TRIOPTICS, the costs incurred shall be borne by the customer. This also applies to hindrances caused by other companies operating on the site.

For work that has to be done outside normal working hours, the customer bears the costs for additional overtime, Sunday and public holiday bonuses for TRIOPTICS employees.

The modification of existing systems can result in downtime and loss of production.

8.2 Installation

Support from the customer is required when installing the system for the scope specified in the order. The following precautions should be taken:

- Connections according to specification (electricity, compressed air, data lines) available at the place of use
- Samples according to specification are provided in sufficient quantity (for 8h production).
- The system is installed at the place of use
- The ambient conditions at the place of use comply with the specifications
- Accessibility for installation work on the system is given
- The customer names contact persons in order to be able to clarify technical and organizational questions during installation.
- It is possible to dispose of packaging material
- Internet access for TRIOPTICS laptops is ensured
- Service socket 230 VAC for laptops are available
- Table and chairs are available at the system for commissioning work

8.3 Training/Operator training

As part of the installation, a practical training session for system operators on the use of the system for regular operation and maintenance for the specified scope can be given. This requires that operation or production is possible and that system operators are present during the installation.

This instruction does not include setting up and using the systems beyond the specified scope, e.g. for new samples and applications or getting to know further functions and adjustments. This operator training also does not include instruction in the fundamentals of the systems with regard to optical concepts or control technology.

8.4 Trial operation

Trial operation, if included in the offer and ordered, means the operation of the system at the customer's premises with all necessary functions.

The customer must ensure the basic requirements for execution of the trial operation are met, such as the provision of sufficient workpieces and materials, as agreed with TRIOPTICS. Operation of the system during the trial operation is to be ensured by the customer in the form of free provision of operating personnel. The trial operation shall be fixed for the period specified in the offer, during which the trial operation must take place on consecutive working days.

Support from TRIOPTICS employees is limited to 8 hours per working day (unless otherwise stated in the offer). For work outside normal working hours or for work that is extended in time (2-shift production) at the customer's request, the customer pays the additional overtime, Sunday and holiday bonuses for TRIOPTICS employees.

9 List of abbreviations

ADAS	Advanced Driver Assistance Systems
CpK	Capability process Katayori (Japanese – "deviation")
DOF	Depth of Focus
EBU	European Broadcasting Union
EFL	Effective Focal Length
EMC	Electromagnetic compatibility
ESD	Electrostatic discharge
ESF	Edge Spread Function
FAT	Factory Acceptance Test
FOV	Field of View
FPN	Fixed Pattern Noise
LGD	Lens Geometric Distortion
MTF	Modulation Transfer Function
OECF	Opto-Electronic Conversion Function
PCB	Printed Circuit Board
RFID	Radio-Frequency Identification
SAT	Site Acceptance Test
SFR	Spatial Frequency Response
SMIA	Standard Mobile Imaging Architecture
SNR	Signal-to-noise ratio
UPS	Uninterruptible Power Supply

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11 Notes

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