EDITION
24/25

SCANNER AND INSPECTION SYSTEMS

Scanner Systems · Inspection Systems · Sensor Heads

Schäfter+Kirchhoff

About Schäfter+Kirchhoff

Schäfter+Kirchhoff was founded over 65 years ago. The company started with classic lens design and customized optical solutions. The focus has gradually shifted to today's product lines: polarization-maintaining fiber optics, lasers for machine vision, as well as line scan cameras and scanner systems.

Schäfter+Kirchhoff GmbH has its headquarters in Hamburg, Germany. From here, high-quality optical products are developed, manufactured and shipped to customers around the world.

Our customers use our products to conduct basic research, work on quantum computers, they are Nobel Laureates, investigate corrosion phenomena, and so much more. We are a supplier to globally important industry sectors including automotive, solar, aerospace, and semiconductor. Our components are integral part of key technologies driving the global economy.

A major focus is the winning combination of high optical and mechanical precision. This is the basis for the high quality, stability and durability of our products. We are committed to providing the highest quality and reliability possible, a goal continuously improving because of our quality control system.

Extensive know-how and highly qualified, dedicated employees are the driving force of our company. Research and development, manufacturing and technical sales all have a strong technical background and are closely linked, ensuring an exchange at an equal level and a fast and efficient response to customer needs.

Schäfter + Kirchhoff develops and builds specialized and customized scanner and inspection systems for laboratory and research applications as well as industrial applications with optimal image quality. All systems are based on image acquisition with one or more line scan cameras.

In the first sections of the catalog we present proven comprehensive measurement and inspection systems. In addition to optimized image acquisition, Schäfter+Kirchhoff has developed evaluation software for the AdheScan and the Corrosion Inspector, which is tailored to the specific application.

Our high-resolution scanner systems and scanner heads can be used for a variety of applications. Standard software is available for all systems to control and acquire raw images.

Individual scanner configurations can be assembled from the modular components found in the third chapter of the catalogue.

The final section presents a selection of successfully implemented scanner projects.

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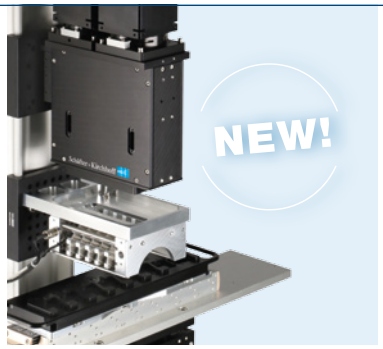
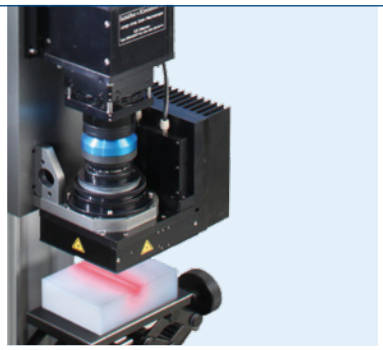
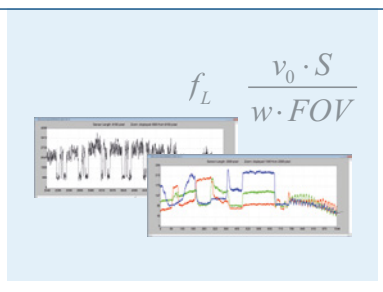


LASM – High-resolution Scanner Systems



Fundamentals



Sensor Heads and Modular Systems

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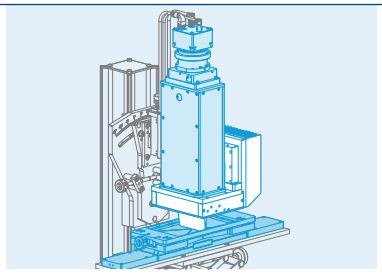

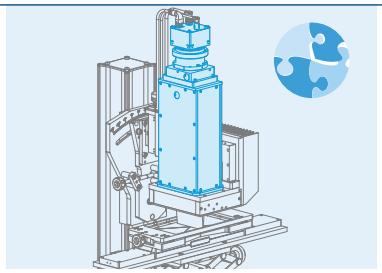

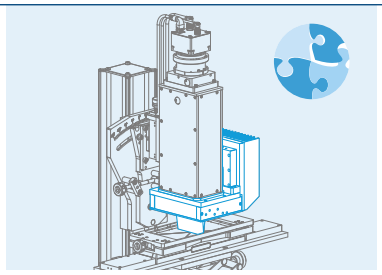

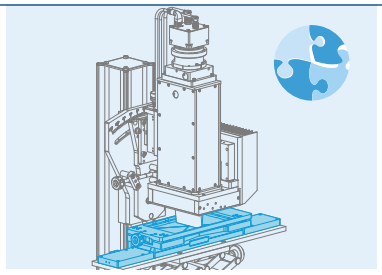

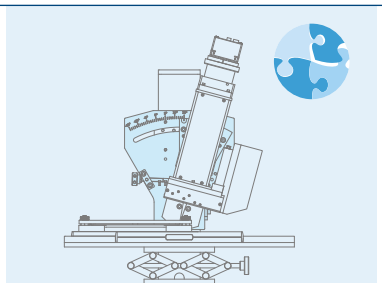

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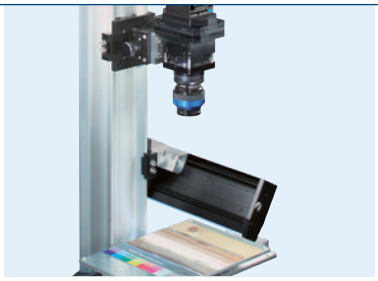


Schäfter+Kirchhoff

Scanner and Inspection Systems

Scanner and Inspection Systems

Corrosion Inspector

Measurement and evaluation of corrosion phenomena on coated test panels

The „Corrosion Inspector“ is a color scanner system for the fast and objective evaluation of filiform and other corrosion phenomena.

It scans a standardized testpanel and delivers a very high-contrast image witha resolution of 0.022 mm per pixel in only 1.2 sec. Using the automatic procedure, the evaluation of asample panel, including documentation and image storage, is completed in 5 sec. In addition to the time savings, the system is characterized by the variety of implemented evaluation methods.

Main features

- Color or monochrome scanner system
- Test panel size max. 100 mm x 200 mm
- Resolution 22 µm/pixel, 1151 dpi
- Automatic and interactive measurement of corrosion phenomena, like area, width, filament length, red rust, delamination, multi-impact.

Specialized evaluation software included:
SKan-CI

Detailed data sheets, up-to-date technical information, technical drawings including step files, accessories, extensive technotes section and FAQs:
www.sukhamburg.com

Technical Data

Total measurement time	max. 5 s
Sensor	3 x 4080 (RGB) or 2048 pixels
Measurement area	max. 90 mm x 200 mm (RGB) max. 80 mm x 200 mm
Resolution	22 µm/pixel (1151 dpi) 40 µm/pixel (650 dpi)
Features	White Balance / Shading Correction, LUT
Interface	Gigabit Ethernet
LED line light	Integrated coaxial LED line light
Scan length	max. 200 mm
Scan velocity	max. 250 mm/s

Corrosion evaluations on corrosion test panels according to

- Filiform corrosion according to ISO21227-4
- Delamination and corrosion acc. to ISO 4628-8
- Cross-cut classification according to DIN EN ISO 2409
- Edge corrosion characteristic according to MBN 10494-6
- Blistering according to DIN EN ISO 4628-2
- Stone impact resistance test according to DIN EN ISO 20567-1
- Counting of all filaments, maximum length l, r
- Evaluation according to GSB, ACT II, Qualicoat

Order Options

Pos.	Order Code	Color	Pixels	Resolution	Scan Width	Illumination
1	SK-LASM-80-40-49-J01	–	2048	40 µm / pixel, 650 dpi	80 mm	Red, 640nm
2	SK-LASM-C-90-22-J050	X	3 x 4080 (RGB)	22 µm / pixel, 1151 dpi	90 mm	White, 5000K

Corrosion Inspector

During the development of coating systems with improved corrosion resistance as well as for quality control of coated components, a large number of coated test plates are produced.

These plates are scribed and then weathered in special climate chambers to start the corrosion. Conventionally, the resulting corrosion phenomena are then manually and visually evaluated, often using a magnification glass with an integrated scale, a very tedious work, which is error-prone and subjective.

The Corrosion Inspector scans a standardized test plate in 0.8 seconds with an optical resolution of 22 microns / pixel. The coaxial line illumination, either as a bright-field or as a dark-field, ensures the high contrast image of the corrosion structures. The software automatically detects the shape, length and corrosion area and evaluates it according to the relevant standards.

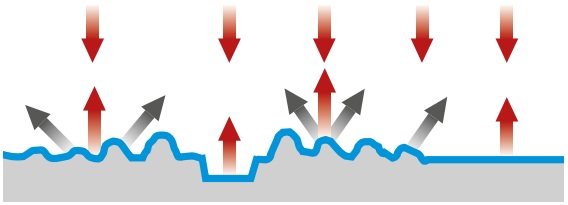
The system was developed for rapid and objective corrosion evaluations with high sample throughput. The automatic evaluation including documentation in an image and Excel sheet takes 5 seconds. The system supports color and monochrome grayscale images.

Bright-field and dark-field illumination

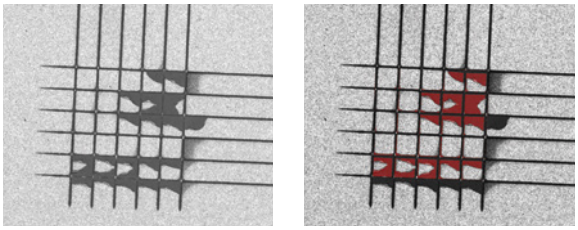
To detect the relevant microstructures, bright-field or dark-field illumination is used.

With bright-field illumination, the light strikes the sample surface perpendicularly. Flat surfaces facing the sensor appear bright, the light hitting the edges is reflected away from the sensor. They appear dark.

With dark-field illumination, the light is directed onto the test surface with an angle. Only light from e.g. edges that cause the light to reflect into the sensor appear bright, flat surfaces e.g. facing the sensor appear dark.



Cross-cut analysis



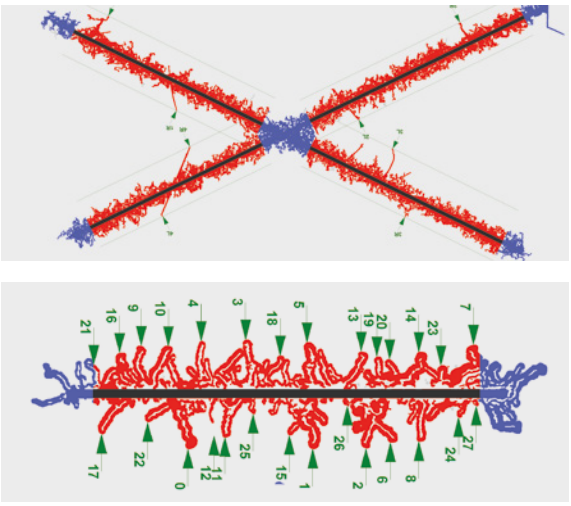
Cross-cut test, delaminated areas are marked in red.

Cross-cut analysis **Date:** 29.04.2021 / 17:04:20

Order:	Article
Exposure time:	800h
Operator:	John Doe

Specimen ID:	01	**SK angle:** 0	
ID	**A [mm²]**	**AD [mm²]**	**Gt**
1	76.33	21.29	3.00

Filiform analysis



Automated evalution of various corrosion parameters of different scribe pattern. Among other things, the infiltration area, the average infiltration width, length and number of threads are measured.

Corrosion Inspector

Analysis and control software SKan-CI

The software SKan-CI offers a simple control for the scanner system. After scanning the test sample, you have a wide range of image processing functions to get the best input for the analysis.

SKan-CI automatically recognizes a predefined set of scribe patterns and also automatically assigns, measures and ranks the corrosion phenomena. When desired, the interactive and manual measurement of corrosive phenomena can be performed by the operator.

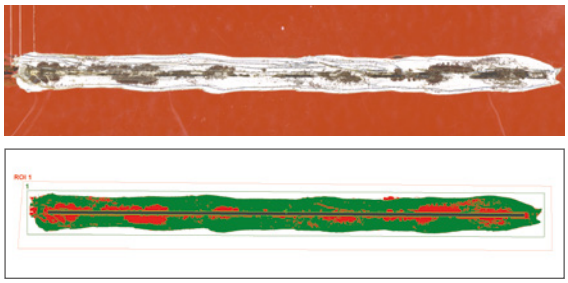
The program saves the accepted corrosion analysis results as images and tabular data, together with the treatment and analytical processing information, for retrieval, comparison and documentation.

The software supports also the offline evaluation, without a connection to the Corrosion Inspector hardware. After loading a stored image, grayscaled or color, the corrosion phenomena can be evaluated with all available methods. This allows an independent reanalysis or a new evaluation.

Software functions SKan-CI

- Control of camera, lighting and motor stage
- Variable scan lengths, measuring in ROI
- Image processing, contrast enhancement, zoom
- Filiform and red rust detection and evaluation
- Exports: original image, binary result image (png)
- Data export to Excel™, LibreOffice Calc

Corrosion and delamination



Automatic evaluation of corrosion and delamination using the color scanner system „Corrosion Inspector“. The Scanner detects red rust areas and measureshe effected area as well es the delamination area. The scribe area is subtracted from both areas.

The sample shown in the picture was kindly provided by the company FreiLacke, Döggingen, Germany.

Korrosion Enthaftung Analyse

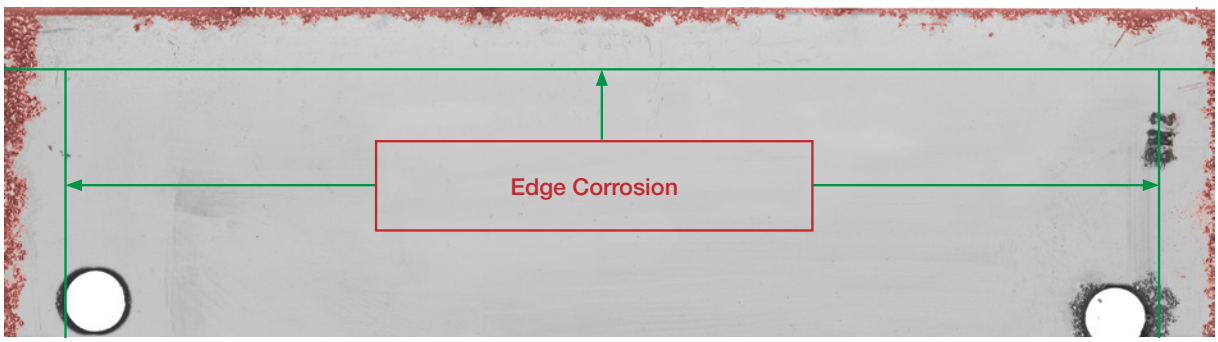
Auftrag:	FreiLacke
Belastungszeit:	1100h
Prüfer:	Mustermann

Proben-ID:	70672B12	**Scanzeit:**	22.02.2018 | 10:23:52
Bemerkung:	Testplatte		

ID	w [mm]	l [mm]	AC [mm²]	C [mm]	AD [mm²]	D [mm]
1	0.82	114.30	191.58	0.84	831.54	3.64
Gesamt	**0.82**	**114.30**	**191.58**	**0.84**	**831.54**	**3.64**

DIN EN ISO 4628-8:2005:
w = scribe width, l= scribe length
*Al = w * l [mm²]*
AC = corrosion area [mm²]
C = AC - Al / 2l [mm]
AD = delamination area [mm²]
D = AD - Al /2l [mm]

Edge corrosion analysis



Edge corrosion, image and result superimposed, the corrosion areas are marked in red.

AdheScan

Adhesive failure surface inspection system

The AdheScan is an advanced, user-friendly comprehensive measurement system for the quantifiable, reliable and reproducible inspection of adhesive failure surface patterns. The system is designed to utilize expert knowledge in an objective and reproducible way. Bond Experts profit from ease of use as well as specially designed image acquisition in combination with trainable machine-learning algorithms.

Ease of use: Intuitive routines, high resolution, 3D height information and 3D view of each fracture pair; scans of up to 8 fracture pairs in one scan

Quantifiable results: Quantifiable, reproducible results for adhesive fracture surface patterns. All results are logged and all relevant data is stored in a database for easy retrieval of previous results

Comprehensive view: Both fracture partners are aligned using the alignment tool and then evaluated together for increased accuracy

Annotation assistant: Bond Experts annotate the sample simultaneously in all 6 views, wherever a pattern is easiest to identify

Advanced algorithms: Machine-learning algorithm for quick and easy sample analysis

Main features

- High-resolution image (11 µm/pixel, 2302 dpi) of up to 8 fracture pairs
- 3D height information with 20 µm resolution
- Annotation Tool with Pair of Assignment: Labeling of the sample is performed in parallel in both the height and high-resolution images and is displayed simultaneously in the 3D image - whereever a pattern is easiest to identify
- Complete inspection in less than 2 minutes
- Semi-automatic mode and process mode. Prediction mode for dealing with very frequently changing substrate/adhesive samples
- All results are logged and all relevant data is stored in a database for easy retrieval of previous results. A pdf file is created automatically containing all relevant information

AdheScan is a further development of a demonstrator, that was developed in cooperation with Fraunhofer IFAM (Department of Adhesion and Interface Research & Quality Assurance and Cyber-Physical Systems) in a project (SAMBA, 20Q1924A) publicly funded by the German Federal Ministry for Economic Affairs and Climate Action (BMWK). The customization for this particular application and the implementation of the machine learning algorithm were made possible through close collaboration and knowledge sharing. The patent is pending (not yet published).

Specialized evaluation software included:
SKan-AD

Detailed data sheets, up-to-date technical information, technical drawings including step files, accessories, extensive technotes section and FAQs:
www.sukhamburg.com

Sample holder

Order Options

Pos.	Order Code	Color	Pixels	Resolution	Height Resolution	Illumination
1	SK-SSM-C-1000	x	2 x 4096 pixels	11 µm / pixel, 2302 dpi	20 µm	White LED

Benefits for Bond Experts

AdheScan provides reproducible, quantifiable results for common adhesive failure patterns. It utilizes two line scan cameras by Schäfter+Kirchhoff (type SK4k-U3DR7C, color, pixel size 7 µm) and provides a high-resolution image (11 µm optical resolution) of both surfaces of the fracture pairs. The cameras are used in a stereo configuration to provide additional valuable height information with a resolution of 20 µm.

Combining the images with the height information, a 3D representation of the sample is generated. The standard system scans up to 8 adhesive failure pairs (8 pairs of substrate and stamp) less than 45 seconds and calculates the height information in approximately 20 seconds.

The complete AdheScan is depicted on page 13. It also shows a typical sample holder with 8 fracture pairs. It is also possible to scan different types of samples with the help of a specially adapted sample holder.

The high-resolution image and the height information are the basis for the subsequent evaluation using a machine learning algorithm.

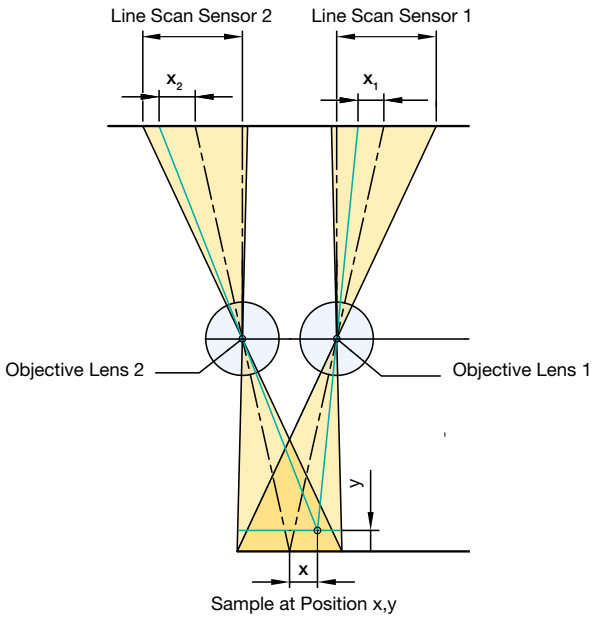
The software allows the user to easily train the machine learning algorithm to automatically evaluate samples in seconds. A well-trained algorithm has a processing time of only about 4 seconds for the evaluation of 1 pair of samples, depending on the computer hardware.

Stereo line scan cameras

The two line sensors are positioned parallel to the sample surface. A difference in height (y) results in a difference in pixel position (x_1 on sensor 1 and x_2 on sensor 2). This so-called disparity x_1-x_2 is the basis for the height evaluation of the image.

A complete 2D image of the surface is acquired by moving the object under the two line scan cameras (e.g. from left to right). The disparity in the line scan signal for each position then leads to a height information for each sample point.

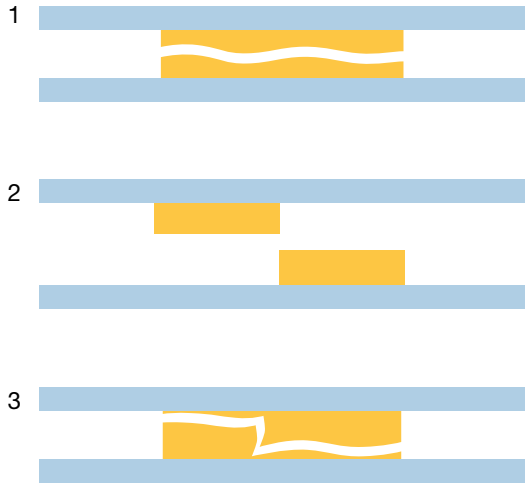
Thus, a high-resolution 2D image of the surface and a height profile are measured simultaneously. The software then takes these two aquisitions to generate a 3D image for each sample.



Bond failure types

The different failure types are defined according to DIN EN ISO 10365 : 2022 Adhesives - Designation of main failure patterns.

Typically, the bond is optimized to break in the adhesive (so called cohesive failure CF (1) rather than at the interface (so called adhesive failure AF, (2). Amongst others, another possibility is e.g. cohesive failure near the surface (SCF. (3).



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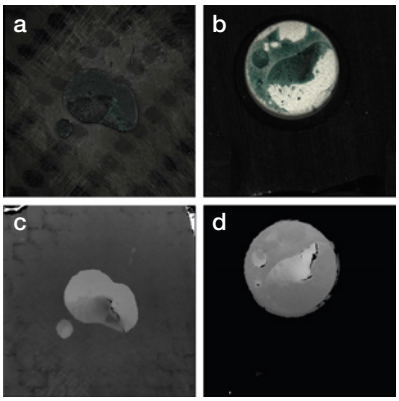
Software SKan-AD: Surface Failure Inspection using AdheScan

The normal procedure for evaluating a set of samples with AdheScan includes several routines inspired by practical experience, e.g. a previously defined ROI set and the input of meta information such as the adhesive used and the substrate materials.

Short overview of the most important steps:

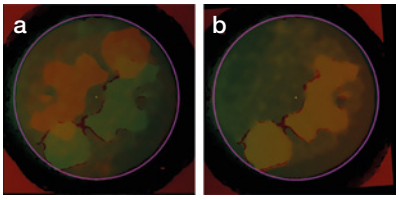
1. Image acquisition

2x2 view with the two high-resolution images of the two fracture pairs and the corresponding display of the height information.



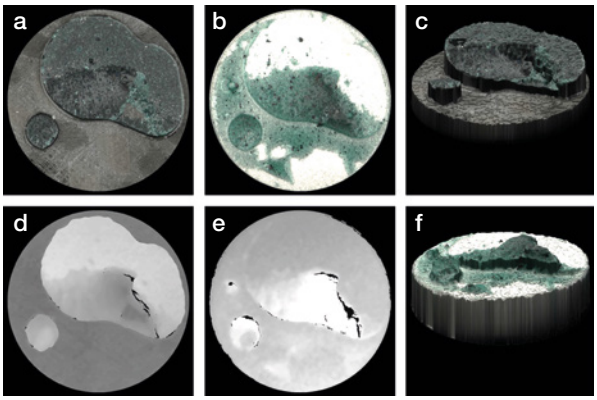
2. Comprehensive view

Overlay visualization for the alignment of both fracture partners - (a) before, (b) after alignment. Enhanced accuracy because all 4 images (high-resolution and height image) must be considered and evaluated together.



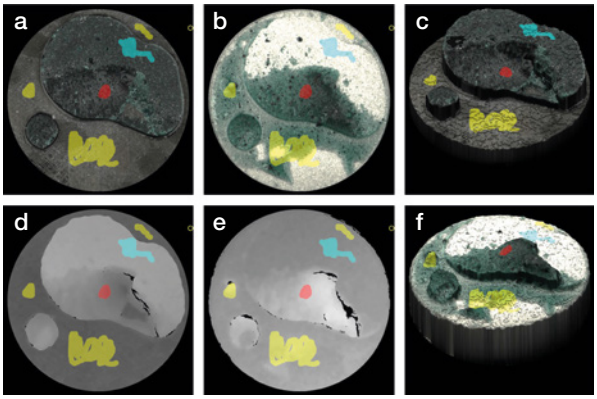
3. 3D image

High-resolution images of both substrate (a) and the stamp (b), height information for both substrate (d) and stamp (e) as well as the corresponding rotatable 3D images of both substrate (c) and stamp (f).



4. Annotating assistant with pair of assignment

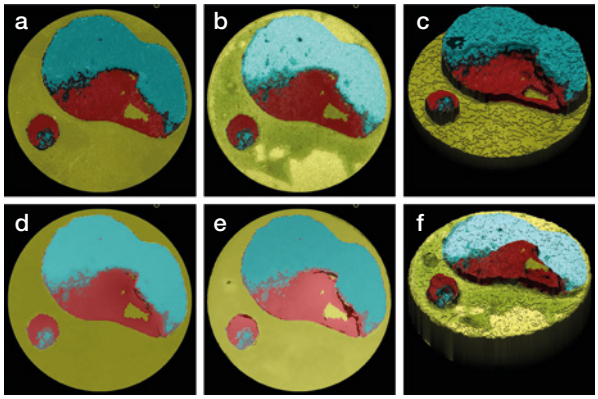
The user marks the fracture classes where the fracture pattern is easiest to identify in either the high-resolution (a, b) or height image (d, e). All other images are marked live for a more accurate results.



Software SKan-AD: Surface Failure Inspection using AdheScan

5. Quantifiable results

Even with only a few markers, the implemented algorithm can make a prediction for the entire image. The complete image is now divided into the corresponding fracture patterns according to the predefined labels, e.g. 25% CF, 35% AF and 40% customized failure type.

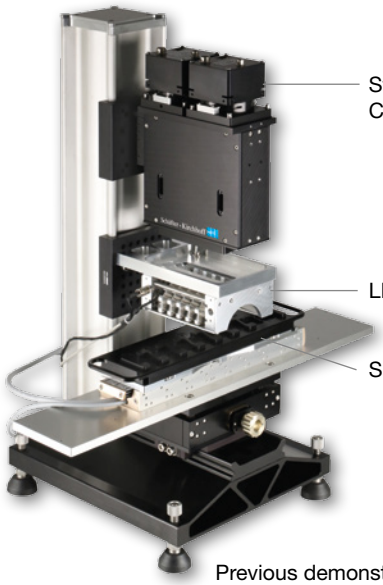


Transferring expert knowledge to the machine-learning algorithm

The annotated images can then be selected as a sample set to be used for teaching the algorithm. Once the data set is selected, the training process of the algoritm can be started. For verification, a portion of the training set is evaluated with the trained algorithm and compared to the manually evaluated results. If the result is good, the process of training the algorithm can be completed by releasing the algorithm. The resulting „skilled“ algorithm can now be selected in process mode to use the machine-learning-assisted fracture inspection.

Qualitiy of the results

The software provides several in-depth features (such as histograms, heat maps, etc.) to evaluate the quality of the result. A threshold value can be defined. This determines whether the analyzed sample is considered a reject. All results are logged and all relevant data is stored in a database for easy retrieval of previous results.



Previous demonstrator from which the AdheScan was developed

Modes of evaluation

The system scans up to 8 adhesive failure sample pairs in less than 45 seconds and calculates the height information in approximately 20 seconds.

Depending on how well the features of both sides are visible in relation to each other, aligning the samples can take anywhere from 30 seconds to 2 minutes.

1. Manual evaluation:

When evaluating samples manually, the time may vary from user to user, depending on the desired accuracy and the number and identifiability of fracture patterns. In general, the evaluation can take between one and five minutes.

2. Process mode:

In process mode, the trained algorithm takes over the evaluation of the images, after the user has aligned them properly. For a typical image size of 900x900 pixels, the algorithm needs about 4 seconds to evaluate the sample. However, this depends on both the image size and the processor performance. A large number of samples, e.g. in-process samples, can now be evaluated in an efficient, reproducible, and accurate manner.

3. Prediction mode:

The prediction mode was developed for laboratory applications when dealing with very frequently changing substrate/adhesive samples.

The AdheScan (here shown in the preliminary housing) contains the following:

- **Stereo Line Scan Camera System**
- **LED illumination**
- **Sample holder**
- **Evaluation Software SKan-AD for surface failure inspection**

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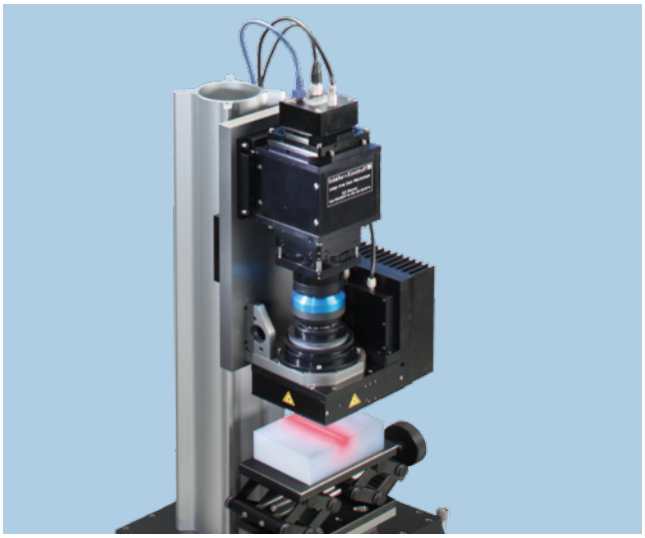
LASM – High-resolution scanner systems

Large Area Scan Macroscope

The images provided by the LASM (Large Area Scan Macroscope) with a resolution of 5 µm have proven to be an essential tool for inspecting microstructures e.g. of ice cores, both in the field and in the laboratory.

Main features

- Monochrome scanner system
- Scan width max. 41 mm
- Resolution 5 µm, 5080 dpi
- High resolution imaging of e.g. ice core samples
- Coaxial directed LED light for bright-field illumination
- Optional: Telecentric lens
- Optional: Direct linear drive
- Optional: Operating temperature down to -40 °C



Detailed data sheets, up-to-date technical information, technical drawings including step files, accessories, extensive technotes section and FAQs: **www.sukhamburg.com**

Line Scan Camera

Time-consuming inspection using a microscope can be replaced by using the specially developed Large Area Scan Macroscope (LASM) with a monochrome Line Scan Camera. The Large Area Scan Macroscope consists of a Line Scan Camera, a high resolution lens as well as an illumination unit. The sample is imaged in reflection with a resolution of 5 µm (5080 dpi). The measuring width is 41 mm with a maximum scan length of 600 mm.

Bright-field illumination

In order to capture the relevant microstructures, brightfield illumination is used. The light directed at the sample is reflected by surfaces parallel to the sensor. Light reflected from structured areas and edges is reflected away from the sensor and appears dark. Thus, also in the images obtained with this method, the grain boundaries appear as dark lines and gas inclusions appear as dark bubbles or spots.

Undisturbed, high quality images in much less time

While for the image acquisition technique using a conventional microscope, thousands of images have to be stitched to form a complete picture, only two or three scans are necessary using the Large Area Scan Macroscope depending on sample dimensions.

This reduces the imaging time considerably and obviates the alignment and matching of the many individual images of these sections, which requires significant computing time. Since the microscope method takes a long time, for scanning ice cores, all images are additionally taken with slightly different contrast due to the ongoing sublimation process, which also needs to be corrected for. In order to stitch the complete picture, the images also have to be corrected for vignetting and distortion.

Using the Large Area Scan Microscope, a shading correction done prior to scanning allows for evenly illuminated images that also do not show significant signs of distortion due to an excellent correction of the field of curvature. Since only two or three images are necessary to cover the whole sample the time required for stitching is severely reduced.

Order Options

Pos	Order Code	Color	Pixels	Resolution	Scan Width	Max. Scan length	Illumination	Special features
1	SK-LASM-C-90-22-R010	–	8160 pixels	5 µm / pixel, 5080 dpi	41 mm	150 mm	Red, 640nm	–

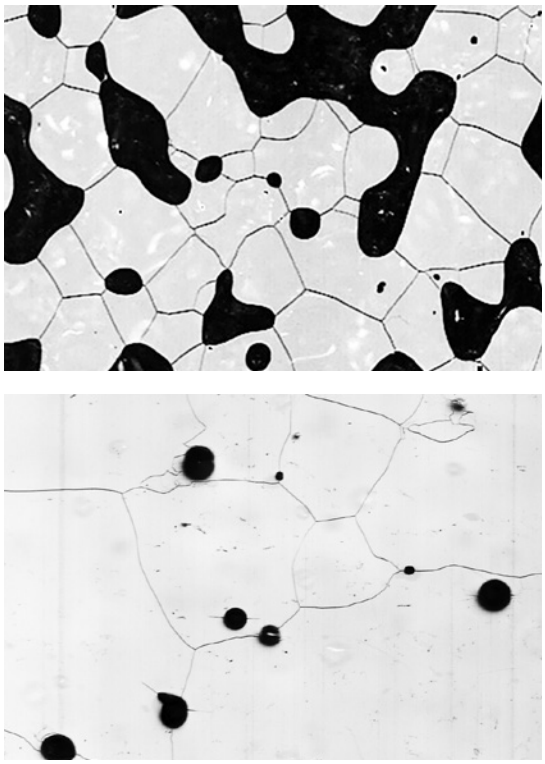
Application: Microstructure Mapping

One of many applications: Ice core inspection

The figure on the right shows the scan of a ice cores sample. The ice core image from 60 m depth shows well defined grain boundaries (dark lines) and pores.

The short time necessary to acquire a complete picture (from >1 h to about 1 – 2 minutes) of an ice core allows for many more samples to be taken during the limited time available in the field, providing a much more detailed picture of the microstructure within the whole ice cores. Due to the short measuring time, many more samples can be measured from one ice core using LASM. Since the image acquisition is so fast, the ice core samples can even be scanned several times to document the sublimation process (for example right after microtoming, and some time later) which is not possible using the microscope technique.

A stratigraphic image that supports dating the ice cores can be obtained using the Intermediate Layer Core Scanner (ILCS).



High-resolution imaging in harsh environments

As the analysis of the microstructure needs to be done in the field during drilling as well as in the lab, the line scanners developed for analyzing ice cores need to be robust and insensitive to the harsh environment. The components used (mechanical, optical as well as electrical) are designed to work properly at temperatures down to -20°C / -40°C. Mobile scanner systems (like e.g. SK-LASM-41-05-49-J01) are stable and robust enough to endure the long and bumpy ride to and from the drilling site and have been used in the field in Antarctica as well as in Greenland multiple times. Whenever drilling is not ongoing they are used in the lab, e.g. at AWI in Bremerhaven.

More information on microstructure mapping of ice cores can be found on https://www.awi.de/forschung/geowissenschaften/glaziologie/werkzeuge/microstructure-mapping.html.

DEEPICE Project

http://pastglobalchanges.org/science/end-aff/deepice

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Schäfter+Kirchhoff

Fundamentals

Fundamentals – Introduction to line scan cameras

What are Line Scan Cameras?

Technotes and Fundamentals
For more information, please refer to the extensive technotes section on: www.sukhamburg.com/support/technotes.html

Line scan cameras are semiconductor cameras used in many industrial environments. The single photosensitive line sensor contains – depending on type – up to 22800 picture elements (pixels). Light energy incident on the sensor is transformed into an electric signal for digitization within the camera.

At 8-bit resolution, the A/D converter transmits the output voltage of each pixel into one of 256 brightness levels, at 12-bit resolution into 4096 brightness levels.

Color line scan cameras provide three separate line signals for Red, Green and Blue with either 3 x 8-bit or 3 x 12-bit per pixel. The digitized output signal is transfered to a computer via various interfaces according to requirements, e.g. Gigabit Ethernet or USB 3.0.

The advantages of a line scan camera include

- high optical resolution of up to 8160 pixels (monochrome) or 3 x 7600 pixels (color RGB)
- high speed of up to 54 kHz line frequency
- flexible parameter setting for the line scans
- synchronizing of each individual line, as well as the triggering of frames
- when focused on the zenith of cylindrical objects, the line scan camera delivers sharp, distortion-free images of the external surface during rotation
- flexible image height from 1 up to 64000 lines per image
- continuous scanning of endless materials such as foils or paper without a time limit.

Image Acquisition

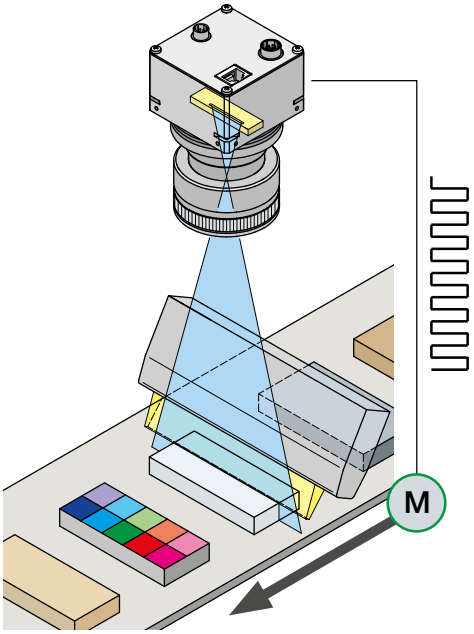
The image produced by a line scan camera is one-dimensional and represents the brightness profile of an object, captured at the current position of the line sensor. A two-dimensional image is generated by performing a scanning movement of either the object or the camera, during which the individual line signals are transferred to the computer and assembled one by one into a 2D image.

Improving the image

High image quality can only be achieved with the appropriate combination of line scan camera, high resolution lens, appropriate lighting and a precise motor unit, whether rotary or linear drive or a conveyer belt. For an image to be correct in all proportions, the scanning speed and the image acquisition process must be highly synchronized and this is most easily achieved by adjusting the transport speed to the line frequency of the camera. However, in practice, it is usually the transport speed and the image resolution that are constraining and these predefine the line frequency and ultimate choice of line camera.

At constant transport speeds, such as when examining objects on a conveyor belt, a line scan camera can be allowed to operate in a free-running mode. Where there are velocity fluctuations or discordant movements then external triggering of the line scan camera is required. The trigger pulses, e.g. from an encoder, are equidistant and independent of the movement velocity so that the camera will be triggered after a constant travelled distance.

This precise synchronization guarantees images with a reproducible resolution and correct aspect ratio.



The production of a 2D image requires precise synchronization of the line camera sensor and the speed of transport of the object.

The line frequency f_L can be calculated for a given object speed v_0 and field width FOV, sensor length S and pixel width w from

$$f_L = \frac{v_0 \cdot S}{w \cdot FOV} \quad (1)$$

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Line Scan Camera Applications

Generally, the applications can be grouped into one-dimensional or two-dimensional measuring tasks.

For one-dimensional applications, the measured result is extracted from the pixel information of an individual line scan. Measurements of two-dimensional images require moving either the object or the line sensor.

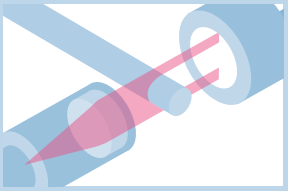
Camera Application:

1-dimensional

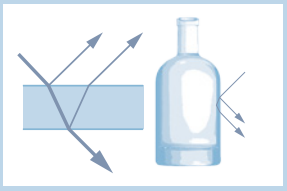
- Signal generation: individual line scan
- Examples: measurement of width, rod diameter, edge positions, glass thickness.

2-dimensional

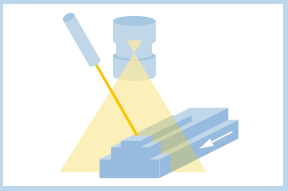
- Several line scans are combined to produce a 2D image (frame)
- Examples: surface inspection, endless webbing inspection, texture analysis, scanning.



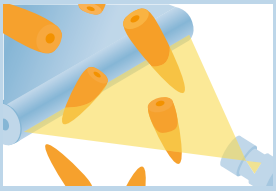
Laser shadow boundaries
Determination of rod diameters, by evaluation of shadow boundaries excited by the laser beam



Glass thickness measurement
Partial reflections at surfaces reach the line scan sensor with distinct timing off-sets that are related to glass thickness.

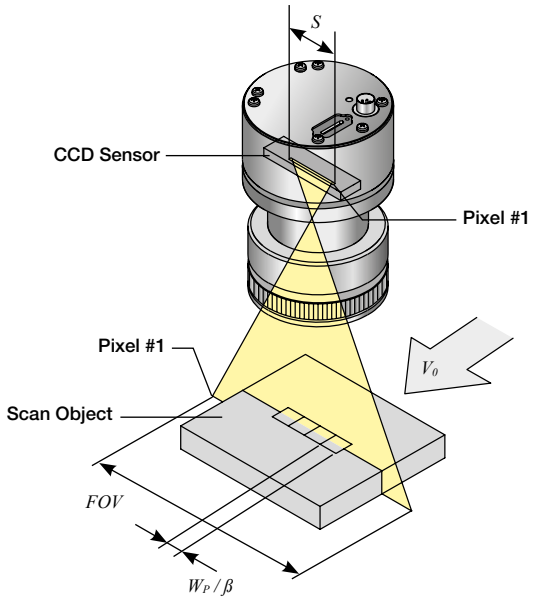


Conveyor belt
A line scan camera can provide height information during object transit using laser triangulation



Screening installation
Objects are sorted according to size or for defects as they drop through a line scan camera field

Optical Resolution



The native resolution of an optical line scan camera is defined by the number of pixels – the row of photosensitive elements in the sensor line. Line scan cameras are available with more than 8000 pixels.

The resolution of the scanner system is determined by the objective lens chosen and the scale of the image β', as a function of the ratio of image size (FOV, field of view) to object size S:

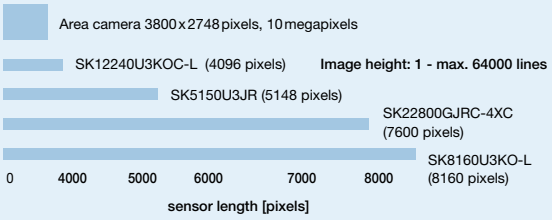
$$\beta' = \frac{S}{FOV} \quad (2)$$

$$p' = \frac{w}{\beta'} \quad (3)$$

Also, to maintain the correct aspect ratio for an image, the pixel resolution p', (3) in the direction of the sensor X-axis must be identical to that in the direction of the transport Y-axis, perpendicular to the sensor. The resolution in the direction of transport is a function of transport speed and the line frequency of the camera as determined in Equation (1).

An identical resolution in both the X and Y-axis directions is an absolute prerequisite for the accurate geometrical measurement of the surface characteristics of the test object. The optical resolution of the scanner system is often reported in dots per unit length, usually dots per inch or dpi.

Comparison: a conventional area camera and various line scan cameras



Synchronization

Synchronization of line scan cameras

In practice, a line scan camera has to be externally synchronized in order to obtain distortion-free images, e.g. triggered by an encoder.

There are two different synchronization functions that can be applied together or individually:

1. **Line synchronization:**
   A TTL signal at the LINE SYNC input triggers each individual exposure of the sensor line by line.
2. **Frame synchronization:**
   The recording of a set of lines (frame) representing a two-dimensional image is triggered by a TTL signal at the FRAME SYNC input.

Line Syncronization Modes:

FreeRun / SK Mode 0

The acquisition of each line is synchronized internally (free-running) and the next scan is started automatically after completion of the previous line scan. The line frequency is determined by the programmed value.

LineStart / SK Mode 1

After an external trigger pulse, the currently exposed line is read out at the next internal line clock. The start and duration of the exposure are controlled internally by the camera and are not affected by the trigger pulse. The exposure time is programmable. The line frequency is determined by the frequency of the trigger signal.

Limitations: The period of the trigger signal must be longer than the exposure time used. Between the external trigger signal and the internally generated line clock, jitter occurs in the range of the exposure time.

ExposureStart / SK Mode 4
(only available when the camera supports integration control)

A new exposure is started exactly at the point in time of the external trigger pulse. The exposure time is determined by the programmed value. The exposed line is read out after the exposure time has elapsed. The frequency of the trigger signal determines the line frequency.

Limitation: The period duration of the trigger signal must be longer than the exposure time used.

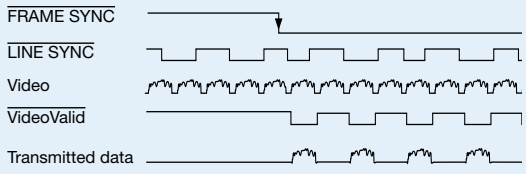
ExposureActive / SK extSOS (Mode 5)

The exposure time and the line frequency are controlled by the external trigger signal. This affects both the start of a new exposure (Start of Scan-Pulse, SOS) and the readout of the previously exposed line.

Frame Synchronization

The camera suppresses the data transfer until a falling edge of a TTL signal occurs at the FRAME SYNC input. This starts the acquisition of a 2D area scan. The number of image lines must be programmed in advance. Any of the available line synchronization modes can be used for the individual line scans.

Timing: FRAME SYNC + LineStart



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Shading Correction, White balance, and Sensor Alignment

Shading correction and white balance

All lenses show some vignetting as a function of the field angle. Hence, even with homogeneous object illumination, the signal intensity of the image decreases with increasing image height.

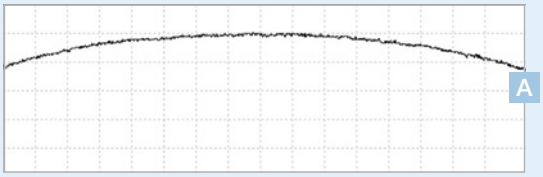
Shading correction (or flat field compensation) is used to compensate for lens vignetting A as well as for inhomogeneity in the illumination. Shading correction is achieved by performing a white balance calibration during illumination of a homogeneous white target.

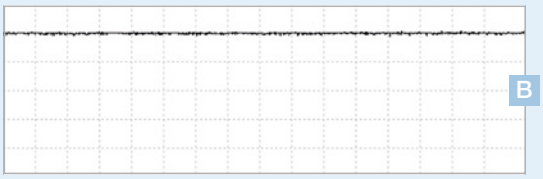
An individual gain for each pixel is obtained by scaling each value to a normalized maximum signal. The oscilloscope display now shows a homogeneous intensity distribution along the entire length of the line sensor B.

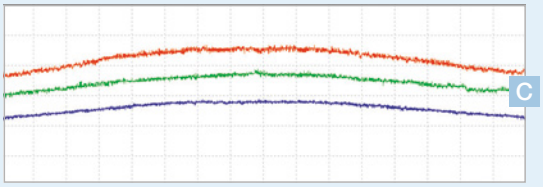
The shading correction procedure is also used for white balance calibrations in color line scan cameras. The different sensitivities of the individual color channels of the sensor are compensated for, as well as any color inhomogeneity arising from the illumination source.

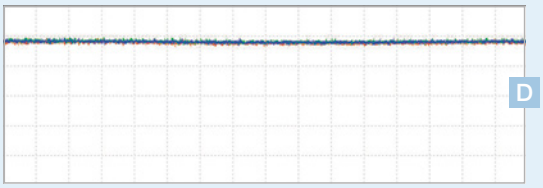
The SkLineScan software package provides all necessary functions for the performance of shading correction and white balance.

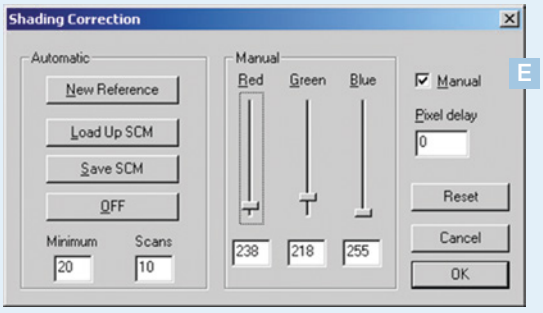
For individual software needs, library functions for shading correction and white balance are provided in the SDKs for the various interfaces.











Shading correction and white balance

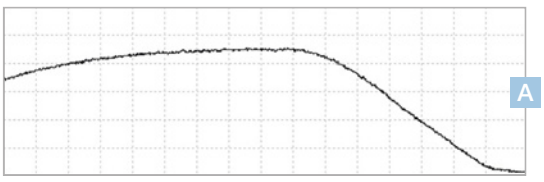
- A A monochrome line scan camera signal of a homogeneous white calibration target showing signal trimming caused by either lens vignetting or inhomogeneous object illumination
- B Monochrome line scan camera signal after shading correction
- C Signal from a color line scan camera of a homogeneous white calibration target showing the effect of trimming on red, green and blue signals
- D Color line scan signal after shading correction
- E Pop-up window for performing shading correction in the SkLineScan software allows white balance calibration to be performed automatically or manually

Sensor alignment

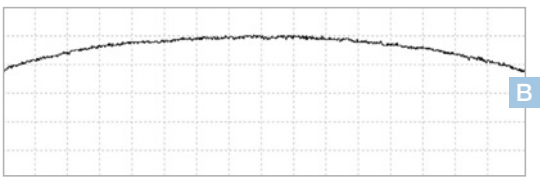
For linear illumination sources, rotating the line sensor results in asymmetric vignetting.

The camera and illumination optics can be aligned optimally by monitoring the object illumination using the oscilloscope display.

A Sensor and illumination optics rotated in apposition



B Sensor and illumination optics aligned properly



Blooming – Anti-Blooming

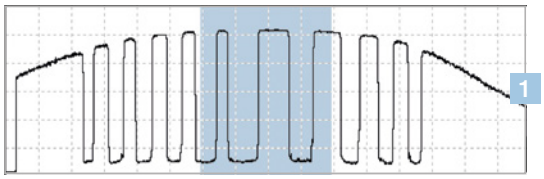
Blooming and Anti-Blooming Correction

When the line sensor is saturated from excessive illumination and cannot accumulate more charges, the overloaded pixels transfer some of the excess charge to adjacent pixels – an effect termed blooming. Blooming leads to the corruption of the geometrical assignment of both the signal and the image generated by the line sensor.

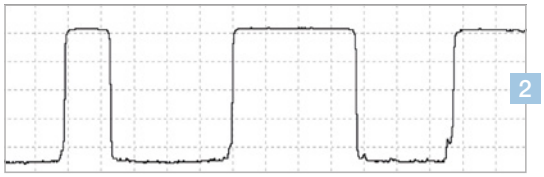
A line scan camera with an anti-blooming sensor can effectively dissipate the surplus charge arising from over-exposure by using a 'drain gate'. The less exposed neighboring pixels are no longer corrupted. Over-exposures of up to 30-fold can be drained successfully, depending on the pixel frequency and spectral range of the line sensor.

Line scan camera signal from a bar code using a midtone incident light and the SK2048U3JR line scan camera without an anti-blooming sensor.

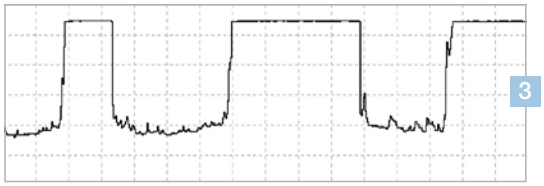
1 Line signal with enhanced illumination of the central range



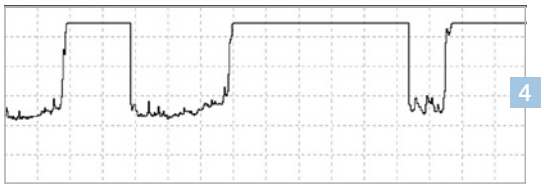
2 Zoom of the signal depicted in 1 showing the steep signal edge



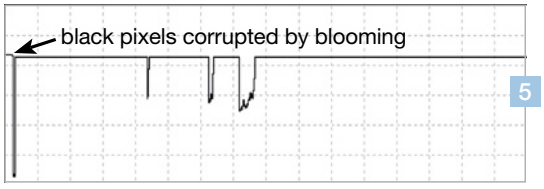
3 Extension of the integration time by a factor of 3.81 produces edges that are no longer vertical and have noticeable shoulders – the blooming of the sensor has begun



4 Over-exposure caused by too large an integration time leads to severe signal and data corruption when using line scan cameras without anti-blooming



5 Extreme over-exposure floods the dark pixels of the sensor, the offset control is disturbed and the line scan camera produces an attenuated signal



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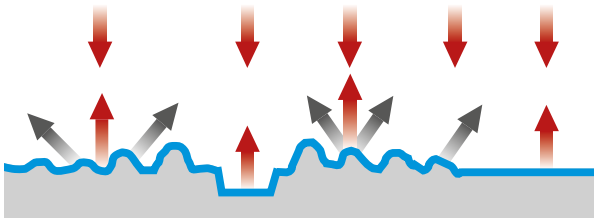
Lighting, true color imaging and telecentric beam paths

Bright-field and dark-field illumination

To detect the relevant microstructures, bright-field or dark-field illumination is used.

With bright-field illumination, the light strikes the sample surface perpendicularly. Flat surfaces facing the sensor appear bright, the light hitting the edges is reflected away from the sensor. They appear dark.

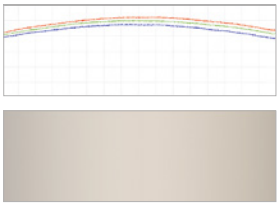
With dark-field illumination, the light is directed onto the test surface with an angle. Only light from e.g. edges that cause the light to reflect into the sensor appear bright, flat surfaces e.g. facing the sensor appear dark.



True color imaging technologies

White balance

A scan of a white template over a defined distance is performed to produce a 2D image. The software calculates a reference curve to correct for variations in brightness. The resulting lookup table is stored in the flash memory of the camera.



RGB raw signal and area scan without white balance

Line signal and area scan with active white balance

Color calibration

For effective color reproduction by the entire scanner, a standardized color calibration is necessary using an IT8-target of a defined color palette. The IT8-target is imaged by the scanner and the software calculates an ICC-profile on the basis of defined reference values.

Subsequent scans can use this profile to produce images with reliable color fidelity.

Zoomed section of the IT8-target, raw data

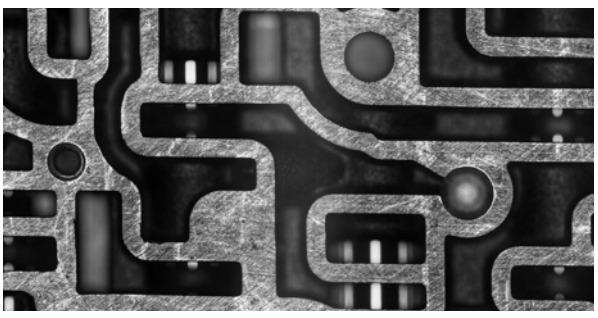
Zoomed section of the IT8-target with applied ICC-profile

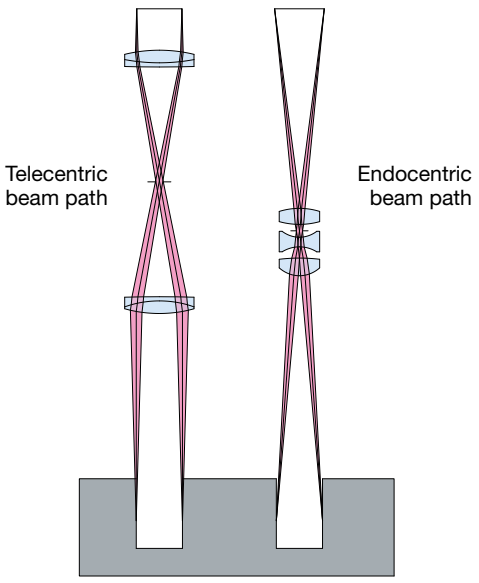
Telecentric vs. endocentric imaging

A telecentric lens views all points of the object directly from above. The resultant image is similar to a 2D technical drawing of the object.

If variations in object height extend beyond the depth of focus then the image may be locally blurred but the object size remains constant.

This makes it possible to determine the width of an indentation without interference by the vertical sidewalls.





Sensor Heads and Modular Systems

Sensor heads and modular systems

Sensor Heads

with integrated line scan camera, optics and integrated coaxial illumination

The sensor heads from Schäfter + Kirchhoff consist of a line scan camera, a lens and coaxial LED line illumination. They are ofthen used for machine vision applications.

Both monochrome as well as color line scan cameras are available. Depending on the application, the appropriate LED line illumination ican be selected (red, 640 nm, for monochrome; white, 5000 K, for color). The included objective lens is chosen to match the specified field of view. Due to the very good coaxial coupling of the LED line illumination into the beam path of the camera, both bright-field and dark-field imaging is possible.

The LED line illumination is supplied by a 24 V DC voltage and can be controlled via LAN or serial interface. The control via an analog input is also possible. Due to the LED Chip-On-Board technology and the low-noise power electronics a very homogeneous and stable illumination is achieved. The passive cooling of the LEDs is also suitable for harsh environments.

- Monochrome camera, from 2048 to 8160 pixels
- Color camera, up to 3x4080 pixels
- Field of view up to 90 mm
- LED illumination: Red or white
- Passive cooling

Detailed data sheets, up-to-date technical information, technical drawings including step files, accessories, extensive technotes section and FAQs:
www.sukhamburg.com

Technical Data

Camera		
Pixels	From 2048 to 8160 / 3x4080	
Sensor type	Monochrome / color (triple line)	
Features	Shading correction / white balancing, LUT	
LED illumination		
Supply voltage	24 V DC	
Max. power consumption	48 W	72 W
Max. LED power, electric	38 W	57 W
LED length	96mm	146 mm
LED width	0.8 mm	
Free working space	49 mm	
Max. temperature	60°C	
Intensity stability	< 0.5%	
Intensity control	LAN / RS232 / Analog input / Trimmer	

Our sensor heads can be configured according to customer's requirements in order to best realize the application.
Please contact us with your individual specifications.

Order Options

Pos.	Order Code	Field of view [mm]	Resolution µm / pixel	Depth of focus [mm]	Free working distance [mm]	LED line color	Supply voltage	Power consumption / LED power	Heat sink orienation
1	SK8160GKO+LED-41-49	41	5.0	0.12	49 mm	Red	24 V	48 / 38 W	Vertical / Horizontal
2	SK8160GKO+LED-60-49	60	7.3	0.19	49 mm	Red	24 V	48 / 38 W	Vertical / Horizontal
3	SK8160G+LED-R-90-01	90	11	0.5	49 mm	Red	24 V	72/ 57 W	Vertical / Horizontal
4	SK8160G+LED-W-90-01	90	11	0.5	49 mm	White	24 V	72/ 57 W	Vertical / Horizontal
5	SK12240G+LED-W-90-01	90	22	0.5	49 mm	White	24 V	72/ 57 W	Vertical / Horizontal

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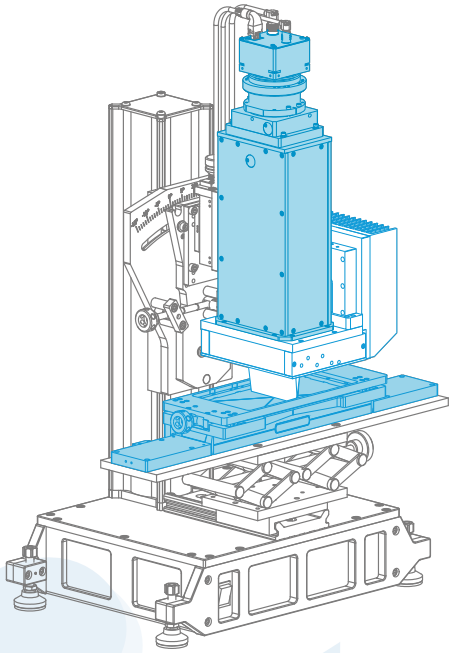
Modular Systems

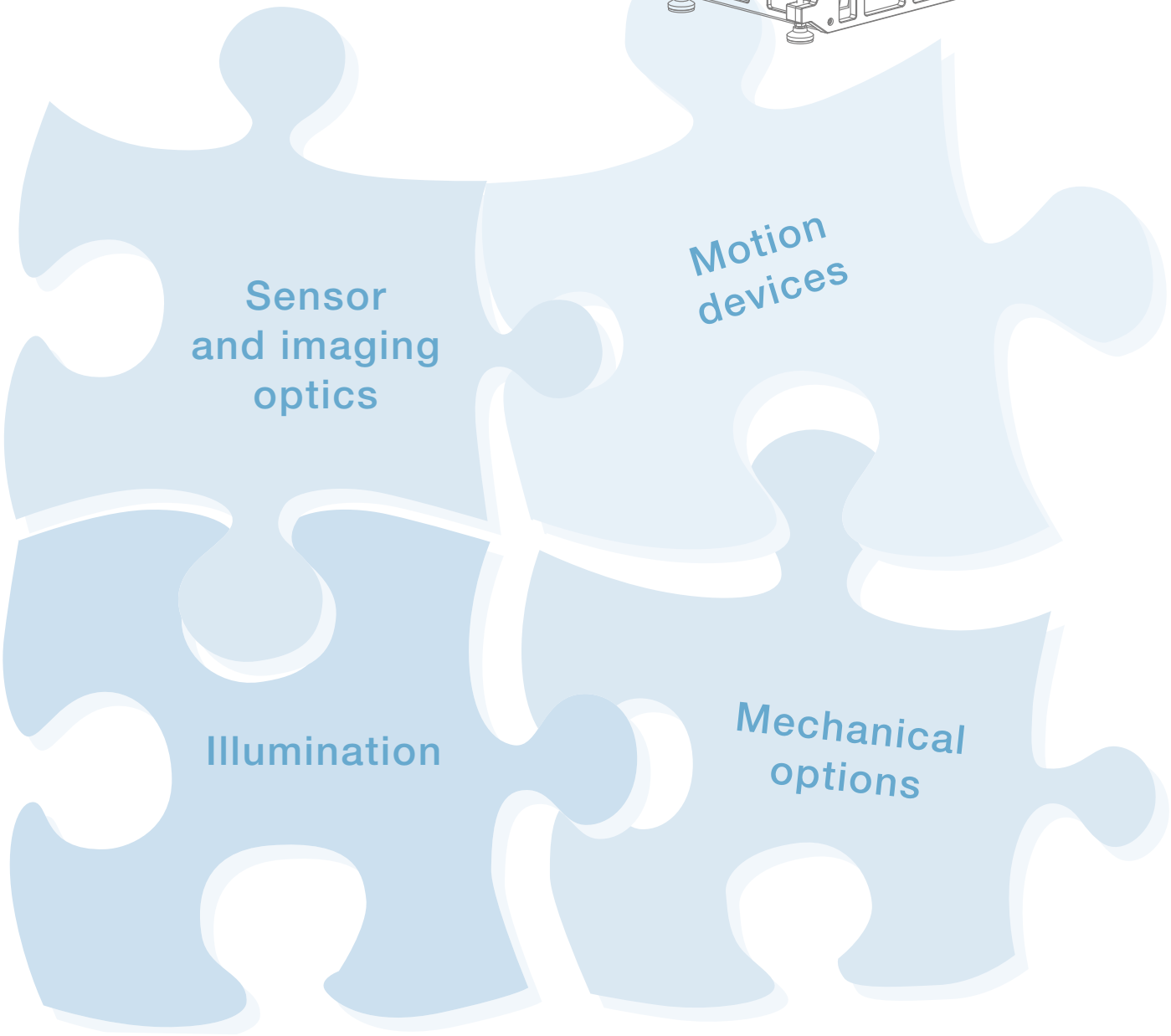
Customized systems based on modular components

The scanner systems are stationary or portable devices for visualization of planar or cylindrical surfaces at high resolution. The resulting monochrome or color images can be evaluated or stored.

Each component is precisely matched to the scanning task.

- Sensor, Imaging Optics
- Illumination
- Motion Devices, Sample Holder
- Software





Sensor and Imaging Optics

Choose specific image field and resolution as well as endocentric or telecentric beam paths

The sensor consists of a line scan camera and imaging optics. The particular configuration determines the field of view, the resolution and the grade of artefacts of the scanned images.

Sensor:

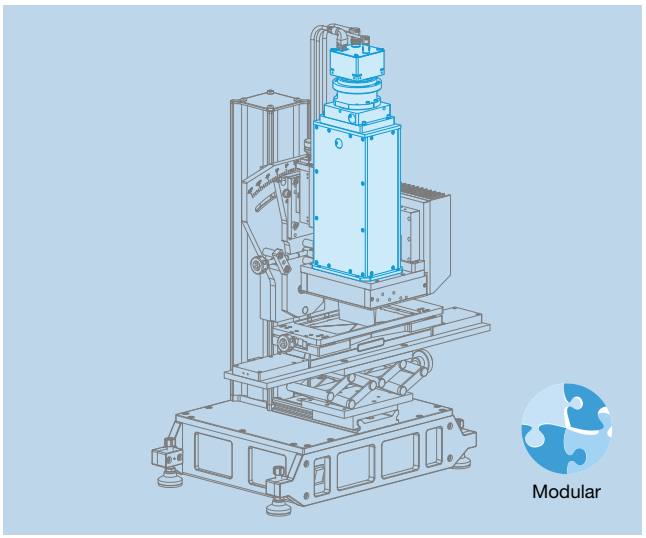
- Line scan cameras monochrome, 2048 to 8160 pixels
- Line scan cameras color, 3 x 2096 to 3 x 7600 pixels (RGB)
- Interfaces: USB 3.0 or GigE Vision

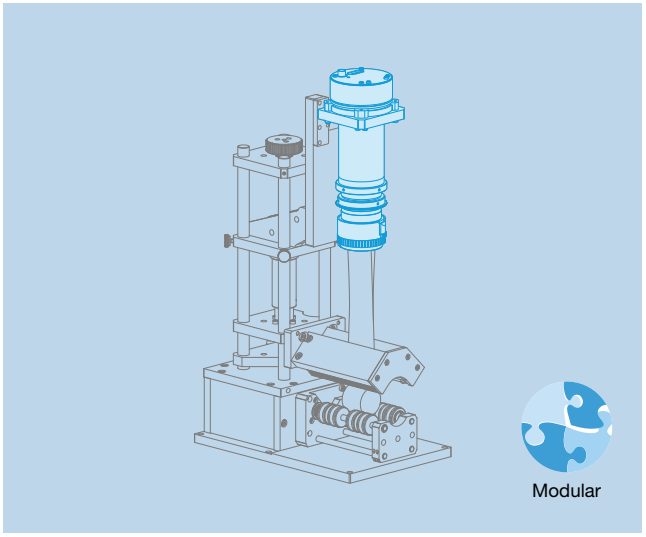
The optics is chosen from a large range of high-quality objective lenses:

- Scan lenses
- High resolution scan and macro lenses
- Enlarging lenses
- Telcentric lenses

Endocentric or telecentric beam paths:

- Endocentric beam paths
- Telecentric lenses and beam paths





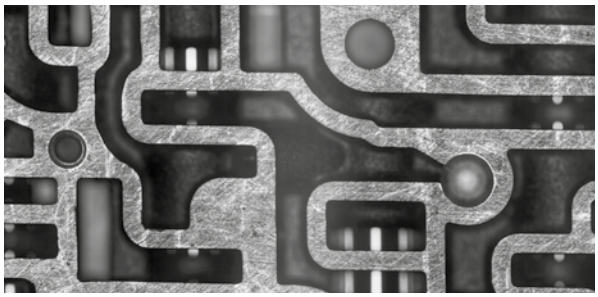
CUSTOM

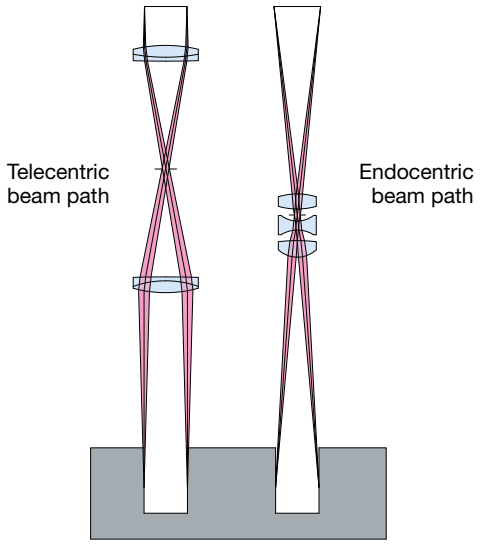
Our modular systems can be configured according to customer's requirements in order to best realize the application. Each component is precisely matched to the scanning task.

Please contact us with your individual specifications.

Telecentric vs. endocentric imaging

A telecentric lens views all points of the object directly from above. The resultant image is similar to a 2D technical drawing of the object.
If variations in object height extend beyond the depth of focus then the image may be locally blurred but the object size remains constant.
This makes it possible to determine the width of an indentation without interference by the vertical sidewalls.





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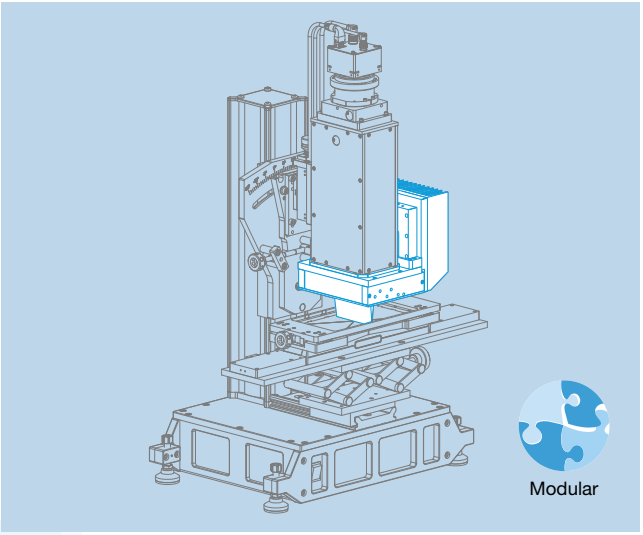
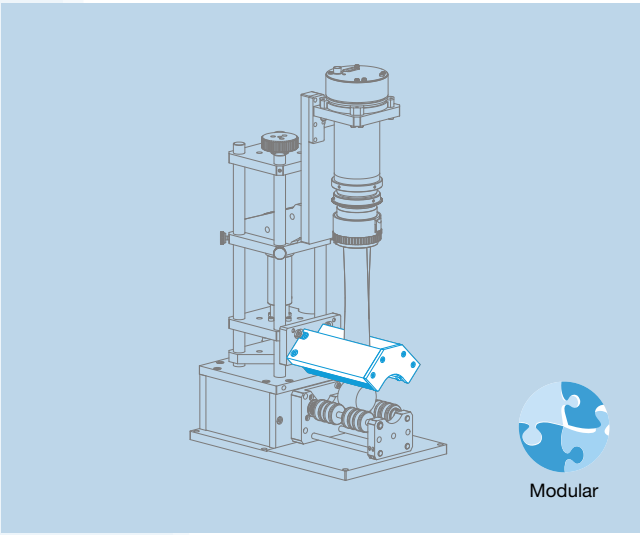
Illumination

Choose from diffusive, directed bright-field illumination or dark-field illumination, coaxial line light or backlight.

The illumination is fundamental whenn producing high contrast images that highlight the distinct features of the measurement task. Schäfter+Kirchhoff offers a vvaierty of different light sources all adaptable to the applicaion:

- Red or white LED light sources
- Coaxial line light
- Backlight
- Diffuse light
- Bright-field or dark-field illumination





CUSTOM

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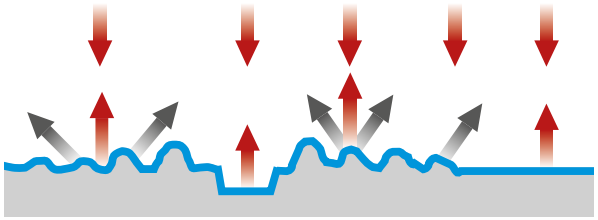
Bright-field and dark-field illumination

To detect the relevant microstructures, bright-field or dark-field illumination is used.

With bright-field illumination, the light strikes the sample surface perpendicularly. Flat surfaces facing the sensor appear bright, the light hitting the edges is reflected away from the sensor. They appear dark.

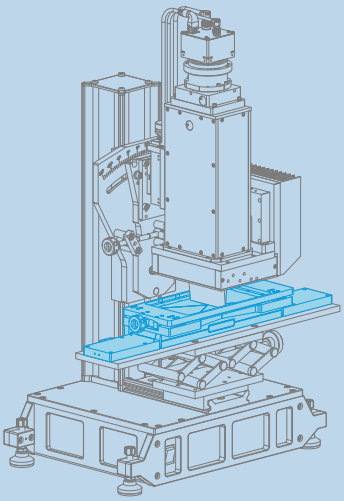
With dark-field illumination, the light is directed onto the test surface with an angle. Only light from e.g. edges that cause the light to reflect into the sensor appear bright, flat surfaces e.g. facing the sensor appear dark.



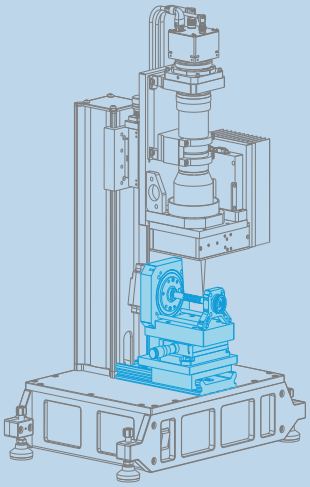
Motion devices

Choose from direct linear drives, spindle drives, or rotational drives.

- Direct drives, load up to 3 kg, scan velocity up to 250 mm/s travel distance 45 to 230 mm
- Spindle drives, load up to 15 kg, travel distance up to 1200 mm, scan velocity up to 75 mm/s
- Rotary drives with pin holder for cylindrical objects Ø 3 to 20 mm
- Rotary drives with roller support for cylindrical objects Ø 24 to 200 mm



Modular



Modular

CUSTOM

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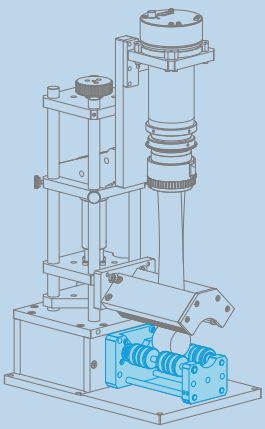
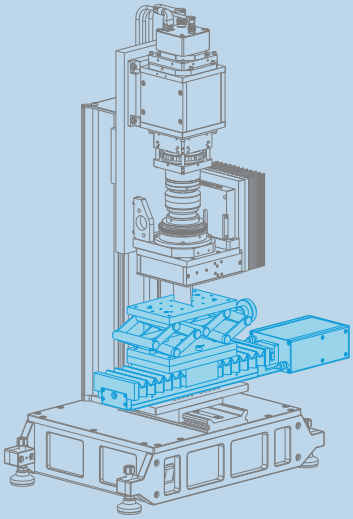


Modular



Modular

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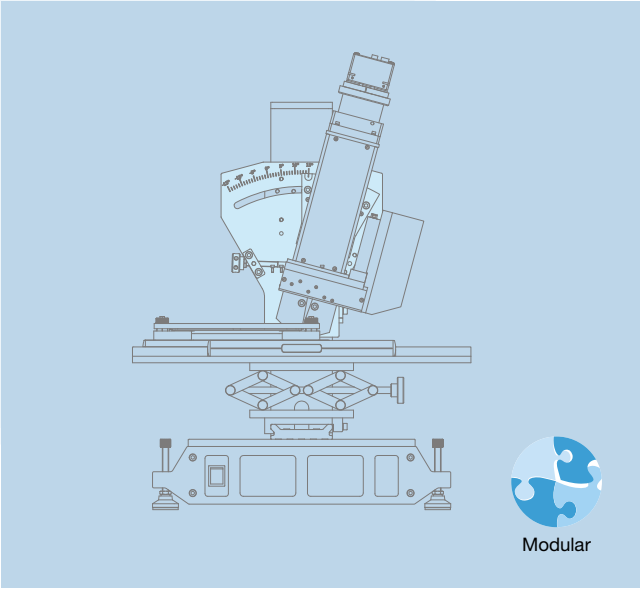
Additional Options

Options: Angle of Incidence Adjustment

for switching to from bright-field to dark-field illumination

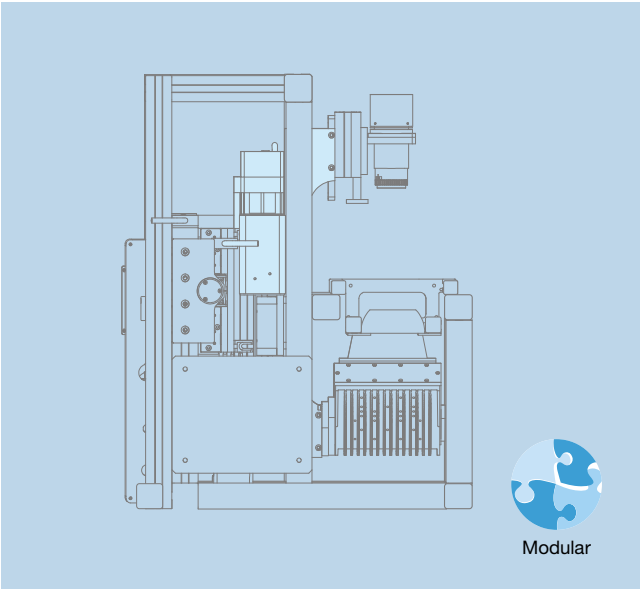
To enable the changeover between bright or dark-field illumination, the sensor mount is available with an adjustment mechanism for the angle of incidence.



Options: Power-driven Working Distance Adjustment

for easy adjustment

Power-driven Working Distance Adjustment.



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Examples – Machine Vision Systems

Customized Machine Vision Systems – Examples

Customized Machine Vision Systems – Examples

In its decades of experience, Schäfter+Kirchhoff has developed a wide range of specialized scanner and inspection systems. Here are some examples of our wide range of customized scanner systems and their machine vision applications in both industrial and laboratory environments.

Example Linear Scanner – monochrome

- High speed translation stage with high positional accuracy.
- Integrated coaxial LED line light, adjustable angle for bright or dark-field illumination
- Powerful application software for visualizing and measuring objects consisting of various materials.

Linear monochrome scanners can be used for surface inspection of planar objects in a wide range of scan widths and resolutions. Typical applications include filiform corrosion, or the measurement of dimension.
Customer requirements determine the camera, lens, illumination unit, and linear motor axis used.
For example, a 100 x 200 mm² wide planar sample can be scanned with a resolution of 20 µm per pixel, or 1154 dpi.

- **Monochrome scanner**
- **Sample size: 100 x 200 mm²**
- **Scan velocity: 250 mm/s, 0.8 s per sample**
- **Resolution: 0.02 mm/pixel, 1154 dpi**

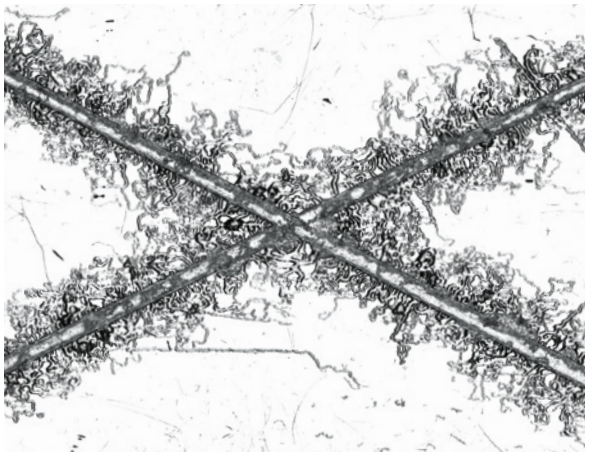
Technical Data

Resolution	22 µm/pixel (1154 dpi)
Scan width (Field of view)	90 mm
Scan length	variable, up to 200 mm
Max. scan velocity	250 mm/s. 1.2 s for 200 mm
Free working distance	49 mm
Depth of focus	3.3 mm at f# 8
Sensor	color line scan camera, 3x 4080 pixels, 10 x 10 µm², line rate max. 4.8 kHz
Light source	coaxial LED line light, white 5000K
Dark-/bright-field adjustment	pivot angle -15° to +15°

CUSTOM

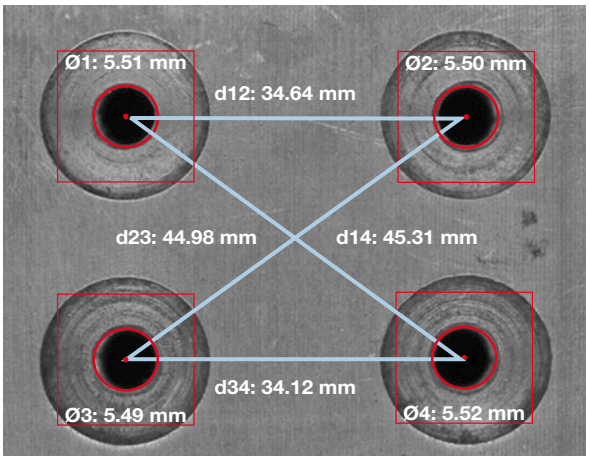
Customer-specific choice of sensor and imaging optics, illumination unit, and motion device. **Contact us to find the best scanner system for your application.**

Sample application: scanning of varnishes



Scanning of varnishes
- High contrast image of filiform and other corrosion phenomenas
- Complete Measurement system, see Corrosion Inspector p. xx

Sample application: measurement of dimensions



Using the linear scanner system from Schäfter+Kirchhoff, the measurement of distances, dimensions and positions of objects is possible.
Ø1 - Ø4: measurement of diameters of holes
d12 - d34: measurement of distances between the holes

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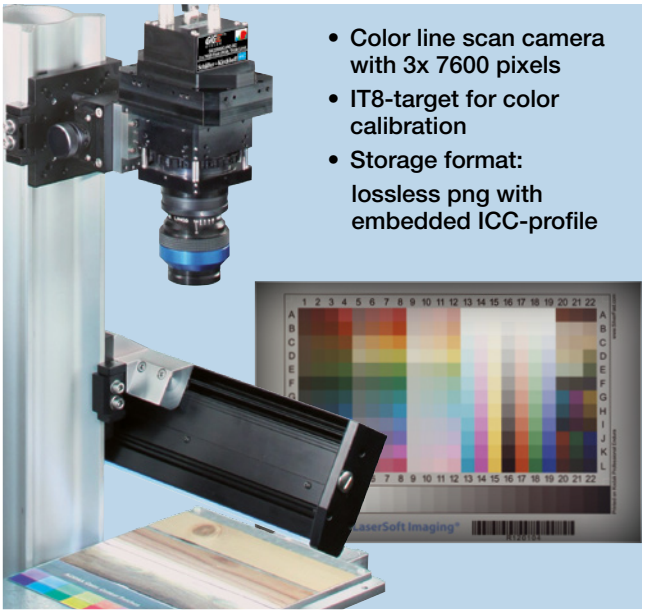
Example Linear Scanner – color

- Color sensors from 3x 2096 pixels (RGB) up to 3x 7600 pixels (RGB)
- LED line light, white
- Scan width up to 800 mm
- Color calibration based on an IT8-target

Linear color scanners can be used for surface inspection of planar objects in a wide range of scan widths and resolutions. Typical applications include wood surface inspection, book and document scanning, and print quality control.

Customer requirements determine the camera, lens, illumination unit, and linear motor axis used.
For example, a 20 mm planar sample can be scanned with a resolution of 20 µm per pixel, or 1270 dpi.



- Color line scan camera with 3x 7600 pixels
- IT8-target for color calibration
- Storage format: lossless png with embedded ICC-profile

Customer-specific choice of sensor and imaging optics, illumination unit, and motion device.
Contact us to find the best scanner system for your application.

CUSTOM

Technical Data

Resolution	30.0 µm/pix (850 dpi)
Scan width (Field of view)	228 mm
Scan length	variable, up to 2000 mm
Max. scan velocity	140 mm/s
Scan duration for 80 x 200 mm²	15 s
Free working distance	405 mm
Depth of focus	2.0 mm at f# 8
Sensor	Color CCD, 3 x 7600 pixels (RGB), 9.3 x 9.3 µm², line spacing 9.3 µm, line frequency max. 4.95 kHz (GigE) or 6.1 kHz (USB 3.0) frequency max. 4.95 kHz (GigE) or 6.1 kHz (USB 3.0)
Light source	directed LED line light, white, 5000 K

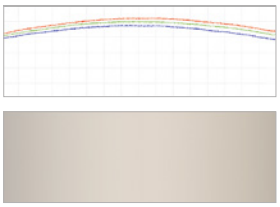
Sample Application: Wood Surface Inspection

Artwork masters for interior decoration (laminate or tilework floor)

True color imaging technologies

White balance

A scan of a white template over a defined distance is performed to produce a 2D image. The software calculates a reference curve to correct for variations in brightness. The resulting lookup table is stored in the flash memory of the camera.



RGB raw signal and area scan without white balance

Line signal and area scan with active white balance

Color calibration

For effective color reproduction by the entire scanner, a standardized color calibration is necessary using an IT8-target of a defined color palette. The IT8-target is imaged by the scanner and the software calculates an ICC-profile on the basis of defined reference values. Subsequent scans can use this profile to produce images with reliable color fidelity.

Zoomed section of the IT8-target, raw data

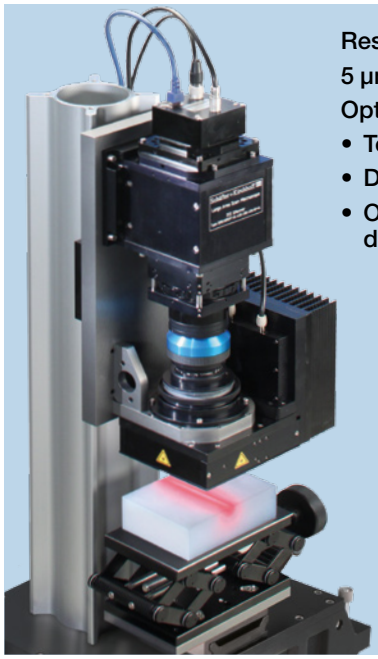
Zoomed section of the IT8-target with applied ICC-profile

Example High-resolution measurements

- High resolution scan lenses
- High resolution telecentric lenses
- Coaxial directed LED light for bright or dark-field illumination
- Operation in harsh environments

This 5 µm high resolution scanner system scans the sample in reflection with a resolution of 5 µm (5080 dpi). The measurement width is 41 mm with a maximum scan length of 600 mm using bright field illumination.

Light directed at the sample is reflected from surfaces parallel to the sensor. Light reflected from structured areas and edges is reflected away from the sensor and appears dark. Relevant structures are imaged with high contrast for easy evaluation.



Resolution:
5 µm/pixel (5080 dpi)
Options:
- **Telecentric lens**
- **Direct linear drive**
- **Operating temperature down to -30 °C**

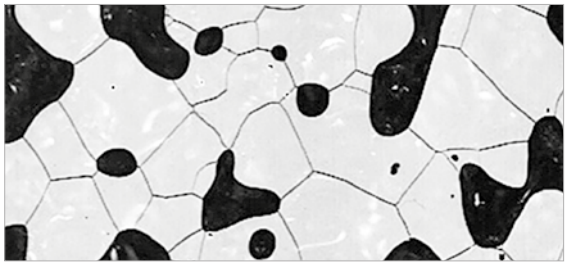
Technical Data

Resolution	5 µm/pix (5080 dpi)
Scan width (Field of view)	41 mm
Scan length	150 mm
Max. scan velocity	59 mm/s
Scan duration for 80 x 200 mm²	2.5 s
Free working distance	49 mm
Depth of focus	0.16 mm at f# 8
Sensor	monochrome CCD, 8160 pixels, 5 x 5 µm², line frequency max. 11.9 kHz
Light source	LED, directed coaxial line light, red 640 nm

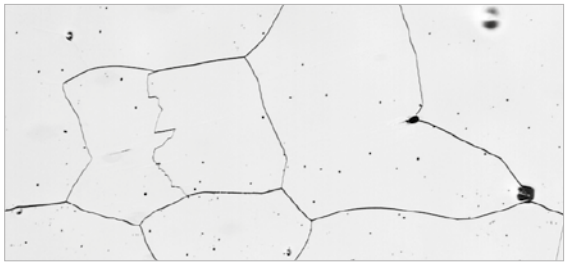
CUSTOM

Customer-specific choice of sensor and imaging optics, illumination unit, and motion device.
Contact us to find the best scanner system for your application.

Sample application: ice core research



Scan of an ice core from a depth of 60 m under Antarctica. The light granular structure and dark gas bubbles are clearly discernable.

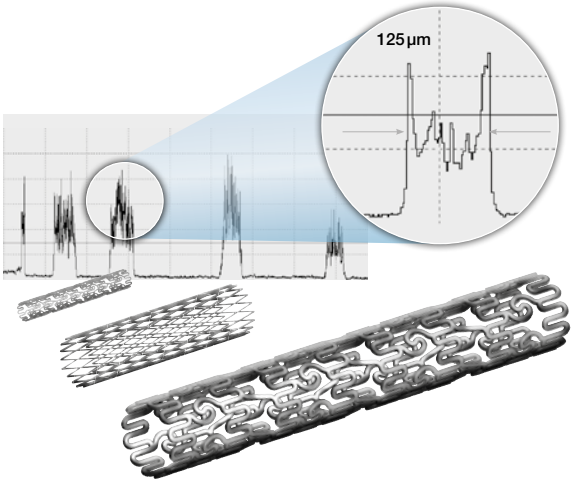


Scan of an ice core from 1035 m deep.

The bubbles have been almost completely transformed into gas hydrates.

Sample application: stent research

Checking stent dimensions and surface quality



Surface quality and dimensions are detected using a telecentric lens and a line scan camera with integrated bright-field illumination.
During stent rotation, the line scan camera rapidly records a planar 2D image of the unwound mesh structure.

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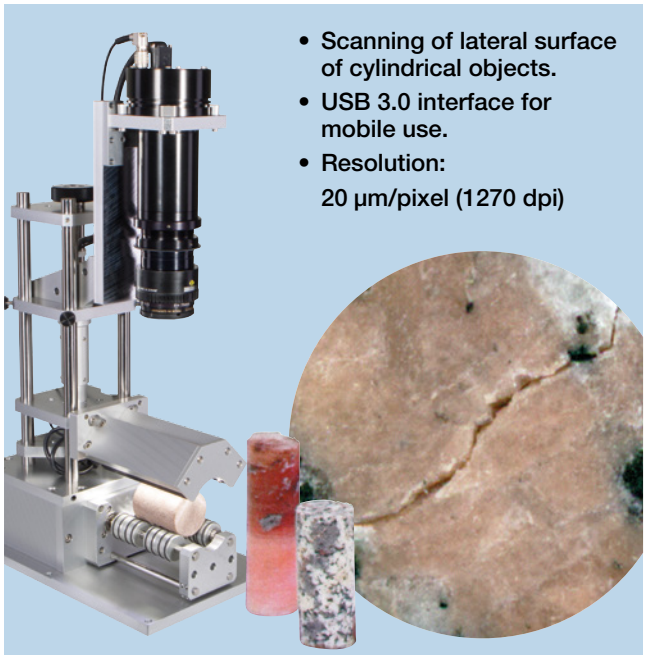
Example Cylindrical objects

- Color sensors up to 3x 2096 pixels (RGB)
- LED line light, white
- Object diameter 10 mm up to 50 mm
- Scan width up to 100 mm
- Color calibration based on an IT8-target

When scanning cylindrical objects, the line scan camera has a significant advantage over other imaging methods, such as using a matrix camera. Focused on the zenith of the round object, the line scan camera delivers sharp, distortion-free images of the lateral surface as the cylinder is rotated.

A color line scan camera with 3x 2096 pixels is used to generate the images. Prior color calibration of an IT8 target ensures that the core connector surface is captured in true color.
The camera's USB 3.0 interface allows the scanner to be controlled by a notebook computer, making the system ideal for mobile use. The roller drive allows for quick and easy loading of zylindrical samples.



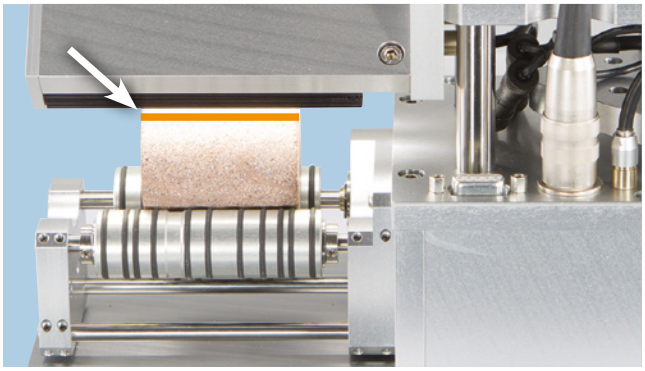
- **Scanning of lateral surface of cylindrical objects.**
- **USB 3.0 interface for mobile use.**
- **Resolution:**
  20 µm/pixel (1270 dpi)

CUSTOM

Customer-specific choice of sensor and imaging optics, illumination unit, and motion device.
Contact us to find the best scanner system for your application.

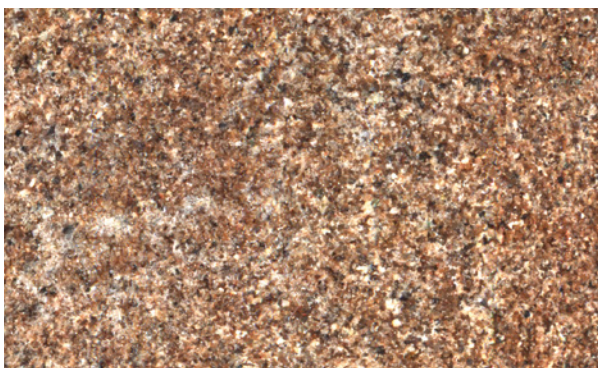
Technical Data

Resolution	20 µm/pix (1270 dpi)
Scan width (Field of view)	41.8 mm
Scan range	360°
Max. scan velocity	66 mm/s
Scan duration for Ø 25 mm	1.2 s
Depth of focus	0.2 mm at f# 8
Sensor	CCD color line scan camera, 3 x 2096 pixels, 14 x 14 µm²
Light source	LED line light, white, 5000K
Rotation	Roller drive



Sample application: scanning of mineral core plugs

1270 dpi distortion-free line scan camera image of a mineral core.



During geological exploration for oil, gas, ores or minerals, a large number of drill core plugs are produced for evaluation. The lateral surfaces of the cores need to be visualized in high quality with subsequent storage of lossless data in digital form.

For mobile applications, the device can be delivered in a robust aluminum case.

You are interested in our OEM Line Scan Cameras?

This catalogue describes specialized and customized scanner and inspection systems for laboratory and research applications as well as industrial applications with optimal image quality. All systems are based on image acquisition with one or more line scan cameras.

If you are interested in our OEM line scan cameras, please refer to **www.sukhamburg.com** for more details.

Or refer to our Line Scan Camera Catalogue for more information.

https://www.sukhamburg.com/support/catalogue.html

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