Telecentric Imaging with Line Scan Cameras

High resolution Imaging and width measurements of stents are possible by line scan cameras.

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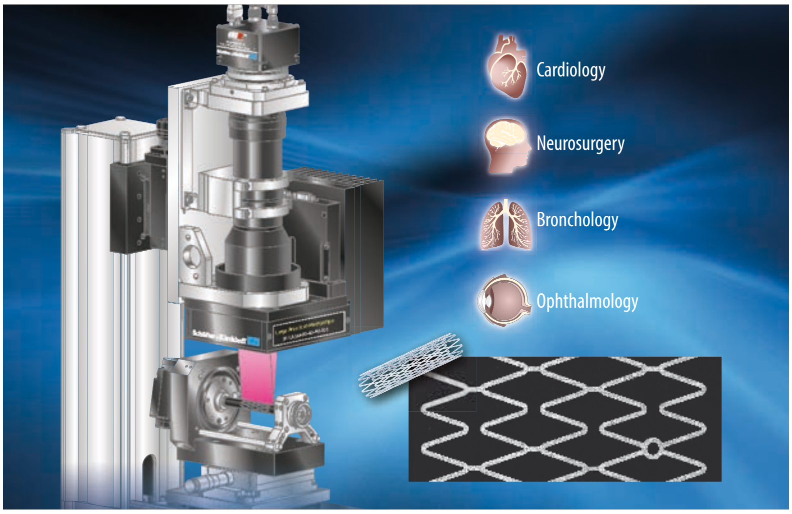
Line scan cameras are used in many industrial applications. In their simplest form they have a single photosensitive linear array. They can either be used for one-dimensional measurements, such as determining the width of a gap, or combined with a scanning movement for producing a two-dimensional image, like in a photocopier or fax machine. The main advantages of such a camera include high optical resolution and speed, the ability to synchronize each line and the freedom to produce an image of almost unrestricted length.



background: Victoria / Fotolia

Fig. 1 Large area scan macroscope with directed bright-field illumination for the quality control of stents.

Images can also be acquired for round objects such as stents by rotating the test sample below the camera (**Fig. 1**). Compared to a matrix camera, especially when scanning cylindrical objects such as stents, the line scan camera has its advantages. Focused on the zenith of the round object, it delivers sharp, distortion-free images of the lateral surface during the rotation of the cylinder.

For the quality control of a stent, a high resolution image of the surface structure and an accurate measurement of the stent structure ridge width are essential. The use of a telecentric lens avoids perspective distortion which is mandatory for exact width measurements.

Image quality is key

In industrial image processing, a high quality image is the prerequisite for successful automated image analysis. Only with a sharp, high contrast and detailed image of the test object the image processing algorithms can perform reliably. The basis of high image quality is the correct choice and combination of line scan camera, lens, suitable illumination and precise motor unit (rotary or linear drive, conveyor belt, etc.).

The image captured by a line scan camera is the brightness profile produced along the line sensor (x-axis). A two-dimensional image is created by translation of the imaged object (y-axis) under the camera sensor. During the scanning movement, the line signals are transmitted to the computer and assembled to a continuous 2D-image. To obtain an image with correct proportions in both axes, the transport speed and the camera recording must be synchronized precisely. This is generally achieved by adjusting the object's transport or rotational speed to the line frequency of the camera. In practice, the transport speed and image resolution are often prescribed and the required line rate dictates the choice of camera.

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 12 000 pixels. The resolution of the scanner system is then determined by the objective lens and the scale of the image ß', which is the ratio of image size to object size.

To maintain the correct aspect ratio for an image, the pixel resolution 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.

Having identical resolution in both directions is essential for the accurate and precise geometrical measurement of the characteristics of the test object, such as gap widths or stent structure ridge width measurement.

Endocentric or telecentric imaging for width measurement?

Both a standard camera lens and the human eye provide an endocentric perspective, so that an ob-

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ject appears to be larger when it is viewed from close up and smaller when further away.

Fig. 2a depicts the beam path of such an endocentric image. When acquiring an image of an object with vertical indentations from above, using an endocentric lens, not only the indentation but also a portion of the vertical sidewalls can be seen. This can confuse the precise determination of object width, cavity size, or ridge width during machine vision measurements and can severely compromise the accuracy of measurement results. This problem is resolved by using a lens with a telecentric perspective.

A telecentric lens (beam path depicted in **Fig. 2b**) views all points of the object directly from above. Variations in object height may result in localized blurring of the image (especially if these extend beyond the depth of focus) but the apparent object size remains constant. It is now possible to determine the correct width of an indentation with greater accuracy.

In telecentric imagery, the front lens must be larger than the object. This can become challenging for larger objects, especially if high optical resolution is needed.

Quality control of medical implants

An example where telecentric imagery can be very beneficial is the quality control of medical implants – in this case stents. A stent is a medical implant, which is inserted into a tube or vessel in order to widen them or to counteract flow constrictions. Every year, hundreds of thousands of stents are implanted in Germany alone. In order to fulfill the specific needs of the various applications, stents are produced in many different shapes and sizes.

In cardiology, stents are used for the treatment of coronary artery disease and have typical diameters of 2 – 4 mm and lengths of 8 – 40 mm. Brain stents are used to treat brain aneurysms or to improve blood flow in narrowing blood vessels (typical diameters 2 – 5 mm, lengths 10 – 20 mm). Airway stents are used to treat a variety of pulmonary diseases (typical diameters 10 – 20 mm, lengths 20 – 80 mm).

Stents are even used within the eye. In an special treatment for glaucoma, microstents are inserted in the Schlemm's canal, the safety relief valve of the human eye (typical diameters 180 – 350 µm, lengths 1 – 12 mm).

The tubular structure of a stent is manufactured from a metal mesh of thin wire, although other materials are also possible.

The stent is imaged during motorized rotation and the signal is recorded by a line scan camera to produce a planar 2D image of the unwound mesh structure. The surface quality and geometry measurements including single ridge widths are needed for quality control assessments.

A stent scanner

The large area scan macroscope consists of a line scan camera, an illumination unit for directed bright-field illumination, a telecentric lens, a motor unit with a rotary device for rotating the cylindrical sample holder and software for control and coordination of motor, illumination and camera (**Fig. 3**).

The stent is placed below the camera for image acquisition. The system is aligned so that the zenith of the stent is directly below and along the view of the line scan camera sensor.

The line scan camera records the brightness profile along this line.

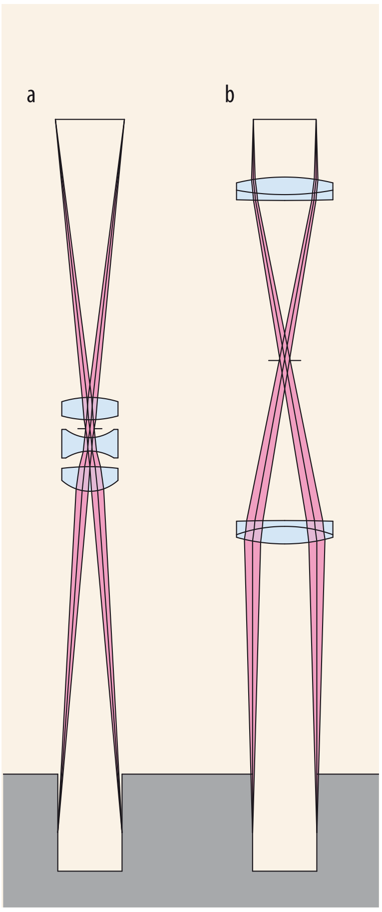

Fig. 2 In endocentric imaging (a), objects closer to the camera appear larger than objects farther away. When viewing indentations, parts of vertical side walls appear in the image and can confuse measurements. With telecentric imaging (b), all objects have the same size, as they are all viewed from above, enabling a correct measurement of the width.

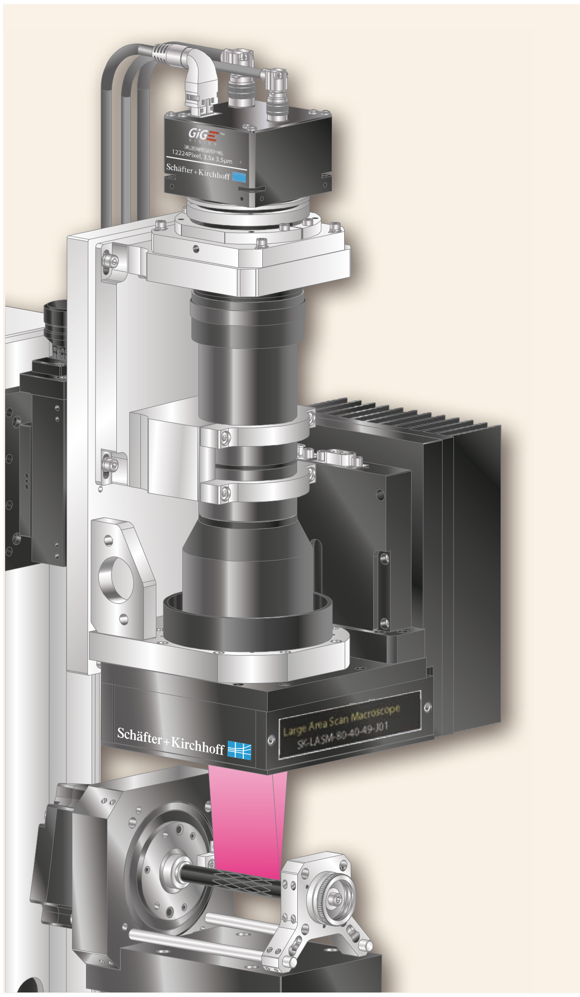

Fig. 3 The large area scan macroscope includes a line scan camera with Gigabit Ethernet interface, an illumination unit for directed bright-field illumination, a telecentric lens, a motor unit for rotating the cylindrical sample holder as well as adequate software for control and coordination of motor, illumination and the camera.

When using directed bright-field illumination, the beam is emitted collinear to the optical axis of the camera lens. The light from surfaces parallel to the sensor is reflected back directly into the camera, producing the lighter areas in the camera image, while textured surfaces and bevelled edges appear dark.

During image acquisition, the rotary motor unit begins to turn the stent under the camera. During this rotation, the single line images are sent via GigE interface to the PC and assembled into a 2D image of the unwound stent structure. The exact synchronization between the object rotation and the camera is key for a reproducible resolution and identical resolution of 3.5 µm in the *x*- and *y*-axis. An undistorted resolution and the use of a telecentric lens produce an image free of disturbing signal from the vertical side walls. So it is possible to measure the width of a single ridge in the stent structure.

Fig. 4 shows the 2D image obtained for the stent structure. The measurement range is 43 mm at a resolution of 3.5 µm. No vertical side parts of the stent structure are visible in the 2D image, so that it provides the optimum conditions to measure single stent ridge widths.

The high resolution also allows stent surface inspection and detection of surface defects. The 2D image shows almost no distortion. The use of high quality components (line scan camera, illumination, telecentric lens) ensures an almost perfect flattening of the field curvature.

Measuring a single stent ridge width

The high resolution and contrast of the 2D image (**Fig. 4a**) with high contrast enables algorithms to measure the width of the single ridges. These algorithms can be based on simple flank detection. But this can only be performed for ridges that are along the line scan image axis. This method is demonstrated in **Fig. 4b**, which shows a typical single line scan camera signal and the zoom depicted in **Fig. 4c**. The high contrast of the image and the very sharp edges are clearly visible.

More commonly used algorithms determine the stent ridge width independently of their angle and position within the 2D image. In this case, the complete contour of the stent structure is determined first. This contour is then used to calculate the width of the single stent ridges for the whole or for certain parts of the image with high accuracy.

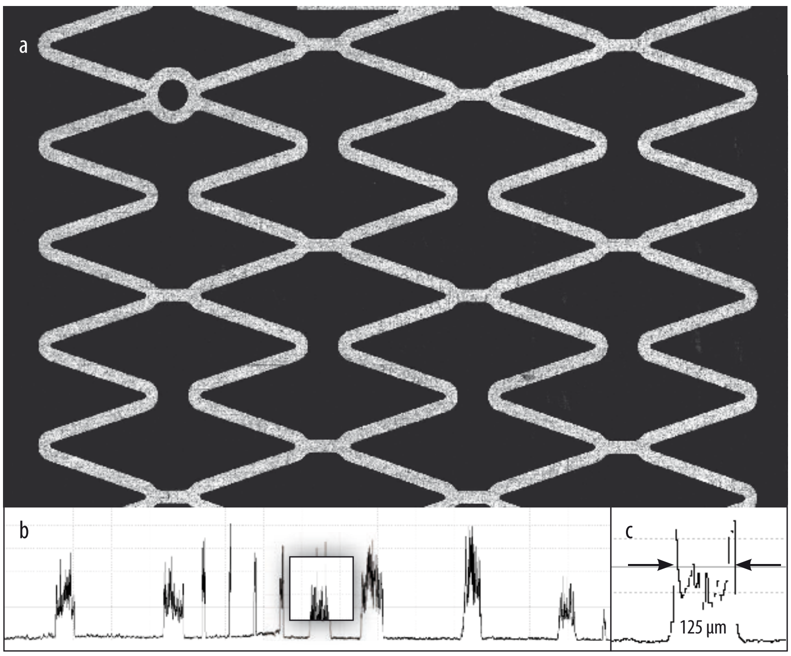

Fig. 4 2D Image (a) of the unwound stent structure at 3.5 µm resolution. The surface defects are clearly visible. The telecentric lens ensures that no vertical side parts can be seen in the image, making it suitable for measuring the stent structure ridge widths precisely. A single line scan camera signal (b) with zoom (c) shows the high contrast and steep flanks of the signal.

Conclusion

A stent is a medical implant, which is inserted into a tube or vessel in order to widen them or to counteract flow constrictions. Quality control is performed with the large area scan macroscope designed and produced by Schäfter+Kirchhoff for validation of these medical implants.

The stent is imaged by a line scan camera during motorized rotation and a 2D image of the unwound mesh structure is acquired. The surface quality and geometry are aquired for single ridge width quality control. The large area scan macroscope consists of a line scan camera, an illumination unit for directed bright-field illumination, a telecentric lens and a motor unit.

A telecentric beam path is critical for determining the width of single stent ridges since the vertical parts of the side walls are then unresolved in the final 2D image. This allows correct determination of the stent contour and accurate and precise measurements of the single ridge widths independently of their position and angle within the 2D image. The large area scan macroscope has a measuring range of 43 mm and a resolution of 3.5 µm.

