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Multisensor Coordinate Metrology

Dimensional Measurement Using Optics, Probes, and X-ray Tomography

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Contents

Sensors

When selecting sensors, the conditions of the workpiece such as the size of the features to be measured, precision requirements and sensitivity to contact must be taken into consideration. Selection of the sensor (or sensors, for multisensor applications) must therefore be done with the measurement task in mind. Economic aspects such as measurement time and costs also play an important role.

Trigger and measuring sensors

1D, 2D, and 3D

The sensors vary a great deal in their mechanical, optical, electronic, and software design, leading to very different properties. Understanding the principles and characteristics is helpful for optimal use. The sensors may have their own measuring range (measuring or scanning sensors) or may only detect a threshold value (trigger sensors) (Fig. 3). The direction of sensitivity of the sensors may be limited to one or two coordinate axes (1D, 2D sensors) or may cover all three axes (3D sensors) (Fig. 4). The measured values of the axes that are not evaluated by the sensor are given by the sensor position (e.g. the location of the measurement axis of the center of the probe tip for 1D probes or the location of the object plane for image processing). Sensors can measure single points (point sensors), contours (line sensors), or surface regions (area sensors) (Fig. 5). All these properties can be found in nearly any possible combination (see Fig. 57, p. 90).

Points, lines, and surface regions

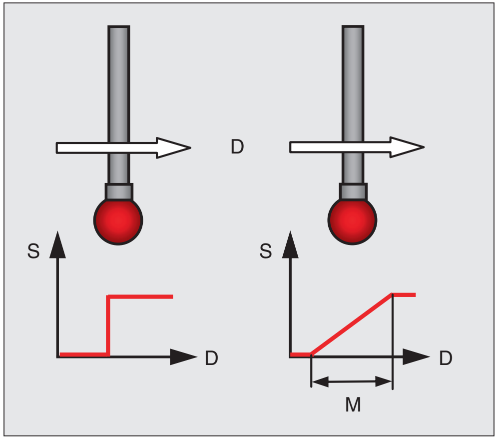


Fig. 3:
Trigger (left) and measuring sensors (right)
D Deflection
S Signal course
M Measurement range

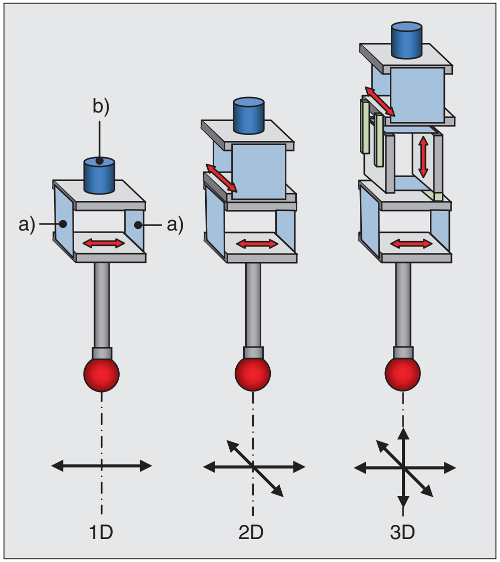


Fig. 4:
One-, two-, or three-dimensional sensors: principle representation of the kinematics without measurement systems
a) Parallelogram spring
b) Mounting cylinder

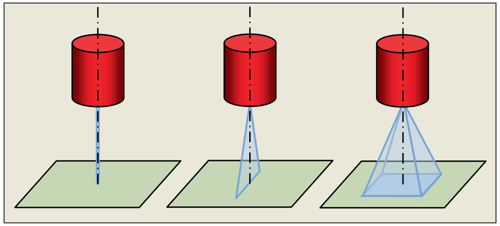


Fig. 5:
Measuring points, lines, or surface regions

Capturing contours by scanning

Scanning contours, for example for measuring form and position tolerances, is possible with measuring sensors (scanning probe, optical distance sensors) when combined with suitable control of the machine axes. Trigger probing systems also offer this function, in principle, but require very long measurement times. When scanning with an image processor, several images are automatically merged during contour tracking to form overall images and contours. The size of the contours that can be scanned is limited not by the sensor, but by the measuring range of the coordinate measuring machine.

Optical, tactile, and X-ray tomography

Another significant criterion for differentiating the sensors is the physical principle of capturing the primary signal. The majority of sensors currently in use can be classified as optical or tactile (Fig. 6). For *optical sensors*, the information about the location of a measurement point is transmitted to the sensor from the object by light. *Tactile sensors* obtain this information by contacting the measured object with a probe tip, typically a probing sphere. With *X-ray tomography sensors*, the workpiece is penetrated by X-rays and its three-dimensional geometry is reconstructed from the X-ray images. The resulting volume data are then used to derive the location of the measurement points.

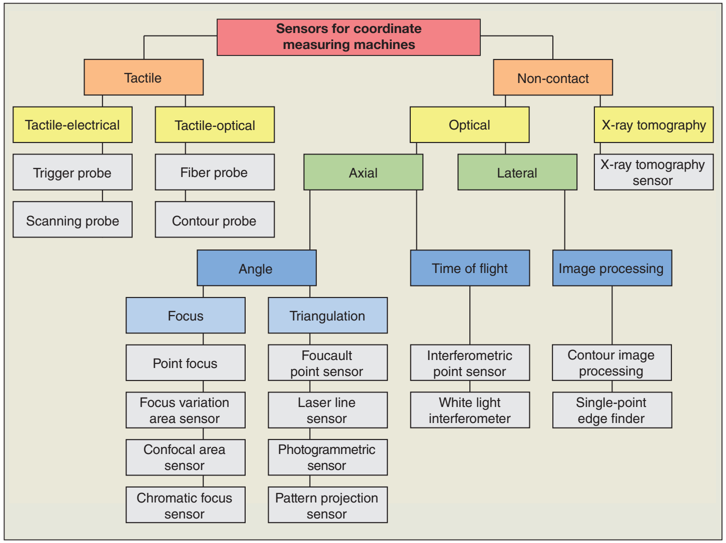


Fig. 6: Classifying sensors according to their physical principle

Optical Sensors

For decades, the human eye was the only available “sensor” for optical coordinate measuring machines, which included measuring microscopes and measuring projectors. Visual measurements led to subjectively induced measurement errors. These included parallax errors (viewing from an angle) and erroneous measurements of light-to-dark transitions (e.g. at edges) due to the logarithmic light sensitivity of the human eye. However, visual edge detection remains the last available alternative even for modern machines. It is used when the object structures to be measured are very difficult to see and the geometric features can only be found intuitively.

Optoelectronics replaces the eye

Generally, the measurement function of the eye is replaced by optoelectronic sensors. Like the eye with a measuring microscope, they act either orthogonally to the optical axis in the object plane (lateral sensors – image processing), or along the optical axis when focusing (axial sensors – distance sensors, see Fig. 6). Lateral measurement sensors determine the distance of object points from the sensor axis (sensor coordinates x, y in the object plane). To do so, the measured object is typ-

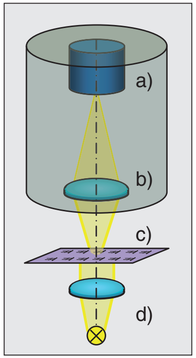


Fig. 7: Principle construction of a laterally measuring sensor with optical imaging
a) Sensor
b) Lens
c) Measured object
d) Lighting

ically illuminated and the image is projected onto the sensor by means of a lens (Fig. 7).

Sensors in this group that measure only individual points allow automated "probing" of edges with good contrast. This means that they are only useful with transmitted light. Due to this limitation, such sensors are rarely used anymore. Today, primarily image processing sensors are used because they can measure many points in the image plane. Images with much lower contrast can be evaluated by considering adjacent structures.

Time-of-flight or angle measurement

Sensors that measure laterally can only be used for measuring two-dimensional (2D) or stepped objects (2½D). To perform a true three-dimensional (3D) measurement of a workpiece with optical sensors, an additional method for measuring along the third coordinate axis is required. The sensors discussed here are known as axial measurement sensors or distance sensors, because they measure the distance between the sensor and the surface of the workpiece. These distance sensors function by different physical principles that can be roughly classified as "time-of-flight" or "angle-based" methods (see Fig. 6). The time of flight of a light beam travelling from the sensor to the object and back cannot be determined directly for such short distances, so an interferometer is used. Triangulation and focus methods use the angular relationship between the measurement beam and the sensor, or the aperture of the optics and the working distance to measure distances (Fig. 8).

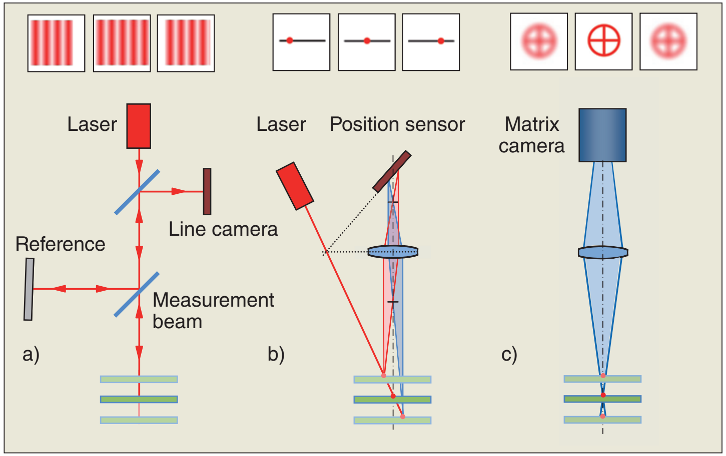


Fig. 8 (opposite): Distance method
a) Interferometer (time of flight): the distance to the object can be determined by interference from the difference in time of flight between the reference and measurement beams.
b) Triangulation (angle): the distance to the object can be determined from the position of the light spot in the measurement field and the known triangulation angle (sensor arrangement according to the Scheimpflug principle to prevent defocusing).
c) Focus method (angle): the distance to the object is determined from the focal state represented by the contrast; defocusing depends on the aperture angle.

The advantages of optical sensors for applications arise from measuring without contact. This means that fragile workpieces, as well as those with small features, can be measured. Plastic parts, functional optical surfaces, flexible sheet metal parts, and micromechanical components (implants, watch parts) are good examples. With non-contact measurements, the difficulty of fixturing small or elastic components can be reduced or eliminated. Many measurement points can be captured very quickly or even simultaneously with optical sensors. Compared with other sensors, they therefore have significantly shorter measurement times. For this reason, they are also used in production control for a wide range of workpieces.

Image Processing Sensors

Due to its wide range of potential applications and good visualization of the object and features being measured, image processing is standard on most optical and multisensor coordinate measuring machines. Like the image generated by a measuring microscope for visual measurement, the measured object is imaged by a lens onto a matrix camera and captured, as shown in a simplified view in Figure 7 (p. 12). The electronics in the camera convert the optical signals into a digital image. That image is used to calculate the measurement points with appropriate image processing software. The light intensity distribution in this image is analyzed. The performance of image processing sensors is significantly influenced by the individual components such as lighting system, imaging optics, semiconductor camera, signal processing electronics and image processing algorithms [1, 4].

Telecentrics for constant image scale

Imaging optics with a telecentric lens produce the lowest measurement uncertainties. The telecentricity keeps the image scale effectively constant when the distance to the object is varied within the telecentric range of the lens (Fig. 9). An aperture is used to ensure that only those beams of light that are nearly parallel are used to generate the image for each image point. This is particularly important for lenses with very low magnification. They have great focal depths, which means that the object can only be roughly brought into focus. The best quality can be achieved with telecentric lenses with fixed magnification.

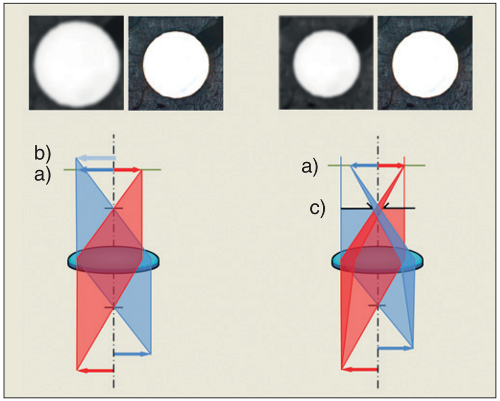


Fig. 9: Non-telecentric images (left) change sharpness and image scale as the object distance changes. With telecentric imaging on the object side (right), in contrast, the images have nearly constant scale.
a) Sensor plane
b) Virtual image plane
c) Telecentric diaphragm

Switching lenses – changing magnifications

For most applications, it makes sense to combine high and low magnification levels. Low magnification, with a large field of view, allows the workpiece to be easily located even if it is only roughly positioned on the measuring machine. Features with less tight tolerances can be measured very quickly “in the image.” There may also be requirements to measure features with tight tolerances using high magnification with high precision and small fields of view. A lens turret can switch the lenses to set various magnifications. The disadvantage is that the position repeatability is often insufficient when changing out optics. Two or more lenses can also be combined by splitting the imaging beam path. Due to the loss of light when splitting the beam, however, certain features may be too dark to be measured. Because only two different magnification levels are typically needed, another elegant approach is to switch between two separate image processing sensors with different magnifications arranged next to each other. They can be simply positioned by the precise machine axes that are already available. The magnification of common telecentric lenses ranges from 0.1× to 100×, with a field of view from 100 mm to 0.1 mm.

Zooming – adjusting magnifications

A zoom optic provides greatest flexibility. Conventional zoom optics move the lens packages to change magnification by means of curved guides in a barrel (Fig. 10a). The mechanical positioning errors caused by moving the lenses results in a loss of accuracy. This can be reduced in several ways. The simplest, but very time-consuming

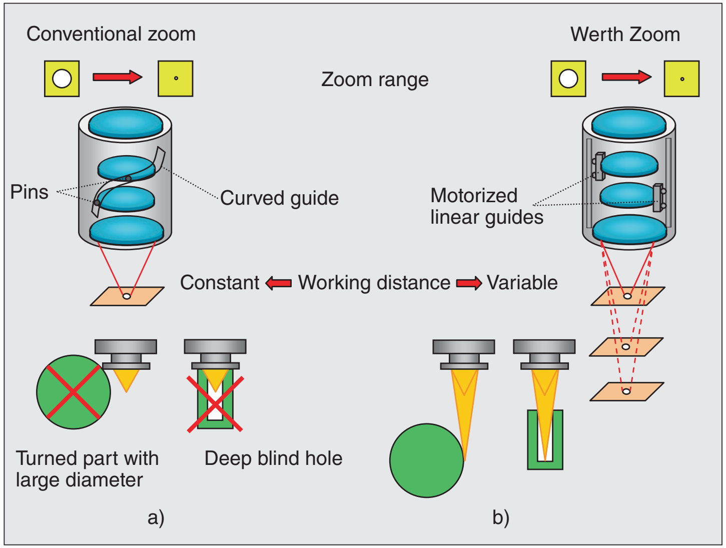


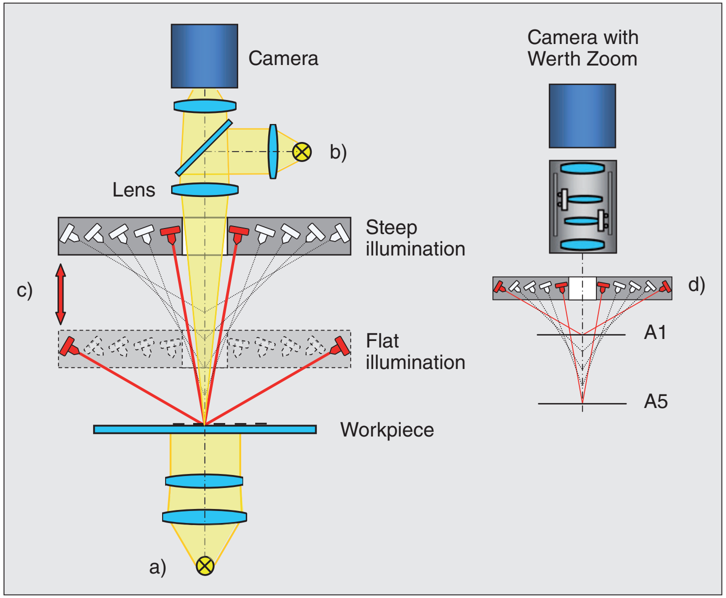
Fig. 10:
Werth Zoom with adjustable magnification and working distance, compared with conventional zoom optics
a) Collision for round parts and deep holes
b) Collision avoided

Werth Zoom: independently adjusting working distance and magnification

method consists of repeated calibration after every change of magnification. Alternatively, high repeatability when zooming can be achieved using motorized linear guides with very low positioning error (Fig. 10b). The mechanical curves are replaced by corresponding mathematical functions in the control software. In addition to different magnifications, this also allows different working distances to be selected. In practice, magnifications from 0.5× to 10× and working distances from 30 mm to 250 mm can be achieved. By selecting the magnification appropriately, the best compromise between the measuring range of the sensor and the measurement uncertainty can be achieved. The working distance can be adjusted largely independently of magnification to meet the requirements of the measuring strategy. This will allow for the most precise measurements and the best image quality with standard working distance or measurements at longer working distances to avoid collisions.

Lighting systems are the basis for every optical measurement and provide the necessary contrast to measure any feature. The easiest features to measure are on the outside edges of workpieces. In this case, *transmitted light* can be used (Fig. 11a). Flat objects provide ideal measurement conditions. On the other hand for edges on prismatic or cylindrical objects, the interaction of lighting, workpiece and imaging beam path must be given more attention. The aperture of the lighting system and the lens must be matched to each other and to the application. Maximum flexibility is provided by transmitted light units with selectable aperture. Panel light sources can be

Fig. 11:
Lighting types
a) Transmitted light
b) Bright field incident light integrated into the lens
c) Dark field incident light MultiRing®, adjustable height for lenses with a fixed working distance
d) Dark field incident light MultiRing® in combination with Werth Zoom: A1: flat light incidence, short working distance A5: steep light incidence, long working distance



Transmitted light aperture as required

used with a mask with many small-aperture holes to create a large collimated light source (Werth FlatLight, see Fig. 47, p. 72).

It is rare that all features can be measured using transmitted light in a practical application. Therefore, additional incident light illumination systems are typically used. There are two different types: The *bright field incident light* (Fig. 11b) is projected onto the measured object parallel to the optical axis of the imaging beam path. Ideally, this is done directly through the imaging lens system. This type of illumination causes direct reflection on metal surfaces, for example, that are perpendicular to the imaging beam path. The measured object is shown as lighted. Inclined surfaces reflect the light away from the lens and therefore appear dark. The *dark field incident light* impinges on the measured object at an angle to the imaging beam path. Depending on the angle of the workpiece surface, the light is reflected into the lens (light) or away from it (dark). The type of lighting can be selected to optimize the contrast of structures of interest on the object. In the simplest case, ring-shaped arrangements of light-emitting diodes (LEDs) are used for the dark field incident light. By connecting various diode groups, the object can be illuminated from different spatial directions and thus optimally adapted to the measurement task (Fig. 11c). Using MultiRing® illumination (Fig. 11d) in combination with zoom optics with a variable working distance (see Fig. 10, p. 16), it is possible to vary the lighting angle to the optical axis over a wide range. Additionally, the working distance to the objects can be long enough for measurement without collision.

Flexible incident light for optimal contrast

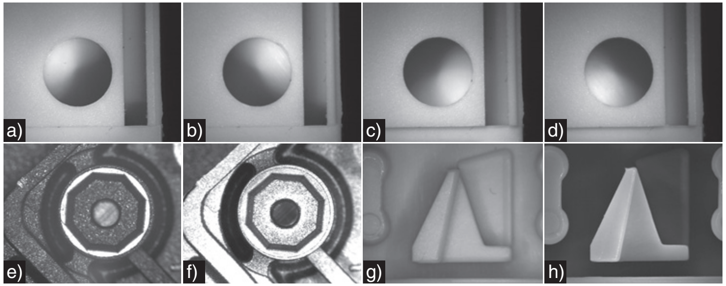


Fig. 12:
Measured object with different types of lighting
a-d) Dark field incident light from various directions
e, f) Bright field and dark field incident light on the same object
g, h) Improving poor contrast (g) with flat lighting using a MultiRing® (h)

Figure 12 shows examples of the effects of different types of lighting. The light sources can be controlled by the user or can be controlled by the measurement software in automatic mode. To measure automatically under practical conditions, variable material surfaces such as metal surfaces with different degrees of reflectivity, or differently colored plastic parts have to be considered. By using a closed-loop light control the lighting will be automatically adjusted until the light reflected by the surface of the workpiece matches the values of light specified by the measuring program. A mathematical correction of the illumination characteristics (light intensity relative to the setting in the user interface) allows CNC programs to be used with various lighting hardware that have different illumination characteristics. This may be on different machines or after a machine repair.

Resolution vs. speed

The images of the object are typically captured with CCD or CMOS cameras. For many years the advantage of CCD cameras compared to their competitors in CMOS design was their high signal quality. The latest generation of CMOS sensors has achieved comparable or even better signal quality. The cameras have from about 700 to 5000 pixels (picture elements) per line at a pixel size of about 5 µm. Cameras with high resolution (many pixels) can capture larger object regions, but are significantly slower than those with lower resolution. A high image frequency is advantageous, for example, when measuring with the focus variation method (see *Focus Variation Sensors*, p. 25) or in OnTheFly® mode (see *Measuring while Moving*, p. 95).

Cameras generate digital signals

Signal processing electronics convert the pixel amplitudes into digital values, commonly called gray scale values. This is mostly done within the camera itself. The signals are transmitted to the computer digitally via GigE or USB.

Filters improve the image

The image processing algorithms used to evaluate the image contents and derive the measurement points also have significant influence on the quality of the measurement results of image processing sensors. Today the evaluation is predominantly implemented with PC hardware and software. As a first step, the image can be improved with image filters, for example to optimize contrast or smooth out flaws in the surface (Fig. 13a, b). The simplest method for determining the measurement points derives the intersection points of predefined lines with the visible contours in the image of the object (commonly called “Edge Finder”). This is repeated sequentially at many locations in a previously specified analysis region (window). The result is a large number of measurement points that are combined into a group within the window. However, a separate one-dimensional analysis is performed to determine each individual point. The extensive two-dimensional information contained in the image is thus not considered. This is a disadvantage, particularly when measuring in incident light. False contours from surface structures, blowouts and dirt can be detected and compensated only to a limited degree.

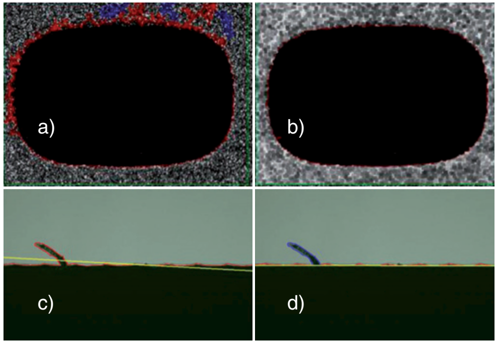


Fig. 13:
Image processing methods
a) Original image: contour detection disturbed
b) Improved with image filter: contour detection correct
c) Erroneous measurement due to contamination
d) Correct measurement including form error with contour filters

Contour image processing for reliable measurement

In contour image processing, the entire image is evaluated within a measurement window. Contours are extracted within this image using suitable mathematical operators. Each pixel on a contour corresponds to one measurement point. The measurement points are strung together like a chain of beads. This makes it possible to detect and filter out artifacts when measuring (contour filter), without changing the shape of the contours (Fig. 13c, d). For practical applications, it is important

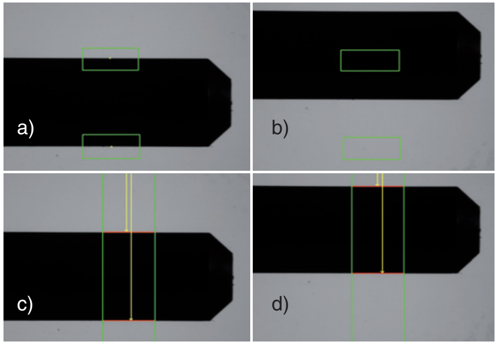
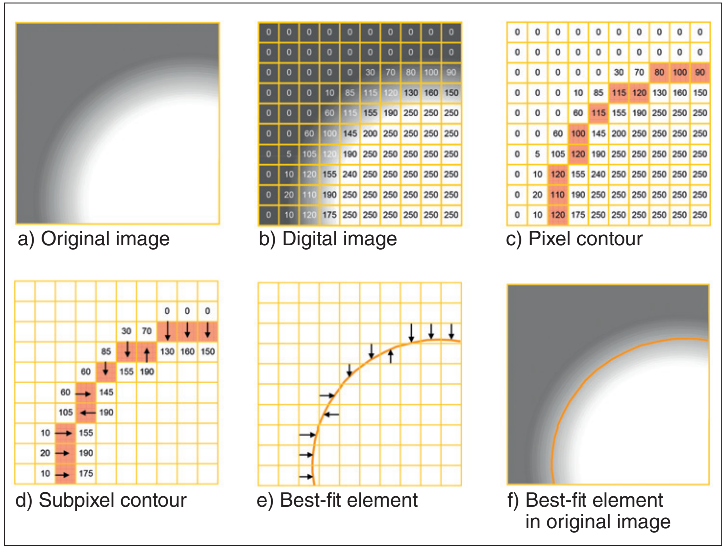


Fig. 14:
Contour image processing compared with single-point edge detection
a, b) Single-point edge detection: correct measurement with exact edge position (a), erroneous measurement when edges are shifted (b)
c, d) Contour selection in a larger window allows the edges to be found reliably in various positions.

that several contours can be differentiated within a captured region (Fig. 14c, d). Modern systems interpolate the coordinates of the measurement points within the pixel raster in an additional step (subpixeling: Fig. 15) enabling higher metrological resolution and accuracy [5].

Contours that are larger than the field of view of the lens being used can be combined into an entire image using automatic contour tracing in conjunction with the CNC axes of the coordinate measuring machine (contour scanning). This scanning method is well suited for checking relatively large contours, such as on punching tools. For this application, both punch and die profiles of the tools can be captured directly and can be compared with each other or with the CAD data set.

Another method for capturing larger areas of the workpiece is "Raster Scanning HD." The image processing sensor captures images of the workpiece at high frequency during the motion of the machine (Fig. 16). These are superimposed via resampling to form an overall image with currently up to 4000 megapixels. With analysis "in the image," 100 holes can be measured in 3 s, for example (see *Sensors and Machine Axes*, p. 89). Measuring large areas at high magnification and averaging over several images, which improves the signal-to-noise ratio, also increases accuracy. The process can be adapted to the requirements of the measurement task (see *Measuring while Moving*, p. 95).



a) Original image

b) Digital image

0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	30	70	80	100	90
0	0	0	10	85	115	120	130	160	150
0	0	0	60	115	155	190	250	250	250
0	0	60	100	145	200	250	250	250	250
0	5	105	120	190	250	250	250	250	250
0	10	120	155	240	250	250	250	250	250
0	20	110	190	250	250	250	250	250	250
0	10	120	175	250	250	250	250	250	250

c) Pixel contour

0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	30	70	80	100	90
0	0	0	10	85	115	120	130	160	150
0	0	0	60	115	155	190	250	250	250
0	0	60	100	145	200	250	250	250	250
0	5	105	120	190	250	250	250	250	250
0	10	120	155	240	250	250	250	250	250
0	20	110	190	250	250	250	250	250	250
0	10	120	175	250	250	250	250	250	250

d) Subpixel contour

e) Best-fit element

f) Best-fit element in original image

Fig. 15:
From the original image to the calculated best-fit element
a) The image processing sensor "sees" the object as a gray scale image.
b) The pixels in the gray scale image are converted into digital amplitudes.
c) A threshold operator calculates a pixel contour from the digital image.
d) For every point of the pixel contour, a "subpixel point" is interpolated from the adjacent gray scale values.
e) The subpixel contour is used to calculate a best-fit element, for example, using the Gaussian method.
f) Display of the result in the gray scale image for visual observation

Raster scanning: resolution independent of the measurement range

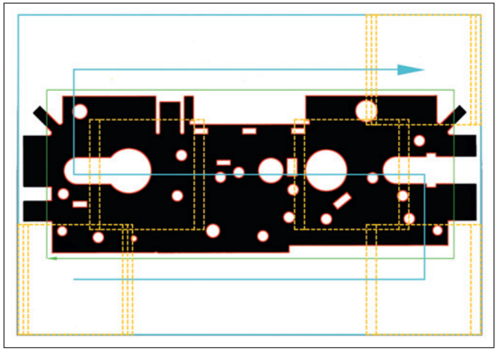
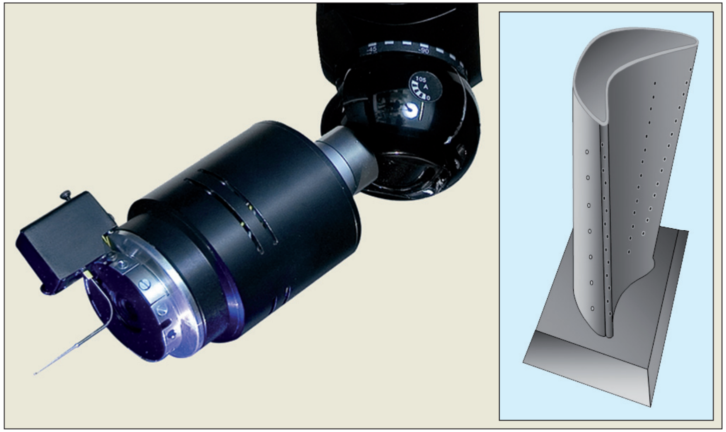


Fig. 16:
Raster Scanning HD: A large number of single images (yellow squares) are recorded while moving along a predefined path (blue line) and merged to form a high-definition image (blue rectangle). All contours (red) in the measurement window (green) are captured automatically.

Image processing was initially suitable only for measuring two-dimensional features. The scope of application therefore included mainly two-dimensional workpieces such as flat sheet metal, films, circuit boards, sliced aluminum profiles, rubber or plastic extrusions, prints, stamping dies, lead frames or chrome masks. The same sensor hardware (optics, camera technology, etc.) can also be used with focusing methods (see *Focus Variation Sensors*, p. 25), to create the commonly used base sensor type for multisensor coordinate measuring machines. By combining both methods in one sensor hardware, many three-dimensional measurement tasks can also be addressed. A major area of application is the measurement of functional dimensions on plastic parts, such as the spacing between snap tabs and the geometry of sealing grooves and plug cavities. Additional application examples are stamped components made of sheet metal, watch components, furniture hardware, fuel injector nozzles, printer heads, tools, and turned components.

To improve the flexibility of image processing sensors for three-dimensional measurements, a rotating and tilting camera head can be used. The standard types of illumination and an automatic interface for the fiber probe are integrated in the head (see *Tactile-Optical Scanning Probes*, p. 45). A rotary/tilt unit, such as those used with tactile sensors, allows the sensor to be oriented spatially relative to the workpiece. An additional interface can be used to automatically exchange various optical or tactile sensors (Fig. 17).

Fig. 17: Tilting sensor with image processing and fiber probe for measuring cooling holes on jet engine components (right)



Focus Variation Sensors

Autofocus and image processing in one

In the simplest version of the focus variation sensor, the measurement point is found by the distance between the object and the sensor. The same hardware components are used for this as for image processing. When moving the sensor along the optical axis, a sharp image is generated in only one position. If the sensor is out of focus, blurry images will result. The contrast can be used as a characteristic value for the state of focus of an image. If the focal plane of the sensor is moved along its optical axis within a range containing the object surface plane, then the contrast value reaches its maximum when the focal plane corresponds to the object plane. The location of the point on the surface can be determined from this sensor position (Fig. 18). This point can then be brought into focus by positioning (autofocus).

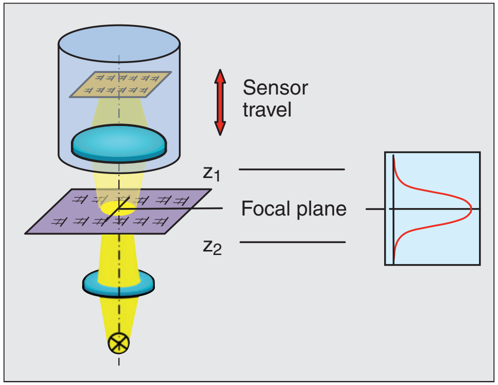


Fig. 18: Determining the focal point by moving the sensor in the range from z_1 to z_2 and evaluating the resulting contrast curve

The sensitivity of the method described is influenced primarily by how far the apparent focal range extends along the optical axis. This range, also known as depth of field,

Contour measurement in workpiece coordinates

used for direct measurements by placing the contour probe into a probe rack. The integration of the tactile-optical contour sensor in a coordinate measuring machine allows fully automatic contour measurements over a large measuring volume. Other advantages are the high precision of positioning the measurement in the workpiece coordinate system and the ability to scan in any direction. This is not possible with classic contour profilometers. The measured data are evaluated for roughness, dimensions, shape and location using software functions. Application examples include: profile measurement of gear teeth segments, embossed sheet metal, profile sections of extruded materials with small geometries, roughness of stamped and punched parts at defined positions, and injection-molded parts.

X-ray Tomography Sensor

X-ray tomography: measuring completely and precisely

X-ray tomography, also known as Computed Tomography, or CT, allows the geometry of workpieces to be captured completely, regardless of their complexity. Both internal and external geometries are captured. Industrial computed tomography had previously been limited to material inspection due to the lack of sufficient precision. This changed through combining X-ray tomography with principles of coordinate metrology in 2005 (Fig. 36). Due to its short measurement times, CT provides significantly faster measurement, acceleration of process chains, and increases productivity for workpieces with many features.

Fig. 36: TomoScope® S: the latest version of the first coordinate measuring machine with X-ray tomography, presented in 2005, optionally with multisensor capability

X-rays penetrate the measured object

X-ray tomography utilizes the ability of X-ray radiation to penetrate objects. As it passes through an object, part of the impinging radiation is absorbed. The longer the length of the object, the less radiation escapes from the opposite side of the object. The absorption also depends on the material. An X-ray detector captures the penetrating X-ray radiation as a two-dimensional X-ray image. With detector sizes ranging from approx. 50 mm to 400 mm, a large portion of the measured objects can be captured in a single field of view even at high magnification.

X-ray images, voxel volumes, and point clouds

Several hundred two-dimensional X-ray images are made in sequence, with the measured object in various accurately rotated positions (Fig. 37a). The object is located on a high-precision rotary axis for this purpose. The three-dimensional information about the measured object contained in this series of images is extracted using the appropriate mathematical process. It is made available as a voxel volume, consisting of many individual voxels. Each voxel (from volume and pixel) embodies the absorption properties, or density, of the measured object or the surrounding air for each defined location in the measuring volume. Similar to two-dimen-

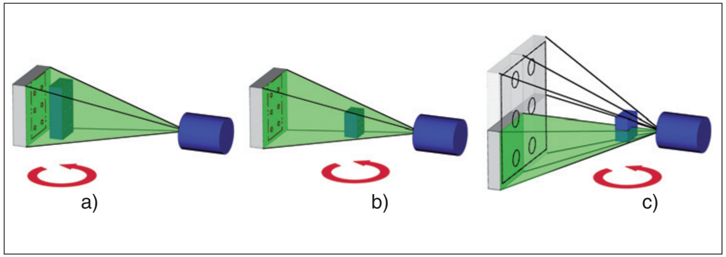


Fig. 37: X-ray tomography: The radiation originating from an X-ray point source passes through the measured object and reaches the area sensor. Images are taken in various rotary positions.
a) Low magnification
b) Higher magnification
c) Raster tomography

sional image processing, the actual measured points are calculated from the voxel data. The boundaries between the object and the air are determined by voxel density and are calculated using an appropriate algorithm. This can be obtained with a metrological resolution and a precision that are fractions of the voxel size ("subvoxeling", [7]).

The sensors currently used capture up to 16 million image points. Typically, several hundred to a few million measurement points at the workpiece surfaces are derived from the measured volume. They are evenly distributed across the surfaces. Geometries in the interior of the workpiece, such as cavities or undercuts, are also captured. The measurement points can be evaluated using the familiar methods and fully integrated software of coordinate metrology.

Raster tomography

Similar to measurement with image processing, it is possible to change the magnification (Fig. 37b). Small parts can be captured at high magnification or larger parts captured completely at lower magnification. To do this, either the measured object's position is adjusted in the radiation path, or the X-ray components (X-ray source and detector) are moved relative to the measured object. In some cases, the size of the sensor or the available number of pixels is not sufficient to capture large parts or small features with adequate resolution. In such cases, the rotary table with the measured object and the X-ray components are shifted relative to each other. Multiple fields of view are then captured. The resulting images or volume segments thus captured are then precisely joined together (*raster tomography*, Fig. 37c).

A variety of applications

The potential applications for X-ray tomography are limited in practice only by the ability to penetrate the workpieces and the precision requirements. This technology has therefore become widespread in plastic injection molding. In addition to the fast first article inspection of many features, deviations from the CAD model can be graphically displayed and easily analyzed. The CAD model for the mold can then be modified or corrected. Using appropriate software functions this can be done manually or automatically. Corrected molds are then produced and process effects are compensated. Practical applications include car headlights, plug modules, cutting edges of shear heads for electric razors and fuel injector nozzles. CT can also be used for inspecting the dimensions of components in assemblies, internal geometries and for analyzing materials (inclusions).

Automated correction of molds

X-ray tomography has developed into an independent technical field within coordinate metrology. The physical background, additional measurement methods, areas of application and the subject of "accuracy" are treated in greater detail in [8].

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The Company behind this Book

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In 2016, Werth Messtechnik GmbH celebrated its 65th anniversary. Quality and precision combined with innovation form the foundation of a successful corporate history. The company's first profile projector set ergonomic standards in 1955. When they were digitized, measuring projectors took on the functionality of a coordinate measuring machine at the end of the 1960s. In 1977 with the Werth Tastauge, the first glass fiber sensor became available for measuring projectors. This principle has become established around the world for measuring with transmitted light. In 1980, the first optical CNC coordinate measuring machine was also brought to market by Werth Messtechnik.

In 1987, a multisensor coordinate measuring machine with image processing and an integrated laser sensor was presented with the name Inspector®. When the VideoCheck® product line was introduced in 1992, the cornerstone for further successful corporate growth was laid. Early integration of PC technology and a strictly modular concept enabled high performance at acceptable prices. Werth Messtechnik has developed into the largest European provider of optical and multisensor coordinate metrology.

Sensor developments like the Werth Fiber Probe® and the Werth Zoom and the world's first integration of X-ray tomography in a multi-sensor coordinate measuring machine in 2005 confirm the claim that Werth Messtechnik GmbH is the worldwide technology leader in this market. Modern developments in the field of software such as BestFit, ToleranceFit®, or WinWerth® AutoElement complete the picture.

Stable growth rates for over several decades have allowed the building of a highly motivated team. Almost 400 employees in Germany, and sales and service support points in major industrial countries, ensure that Werth Messtechnik will continue to provide cutting-edge coordinate metrology in the future, with the best quality and excellent service.