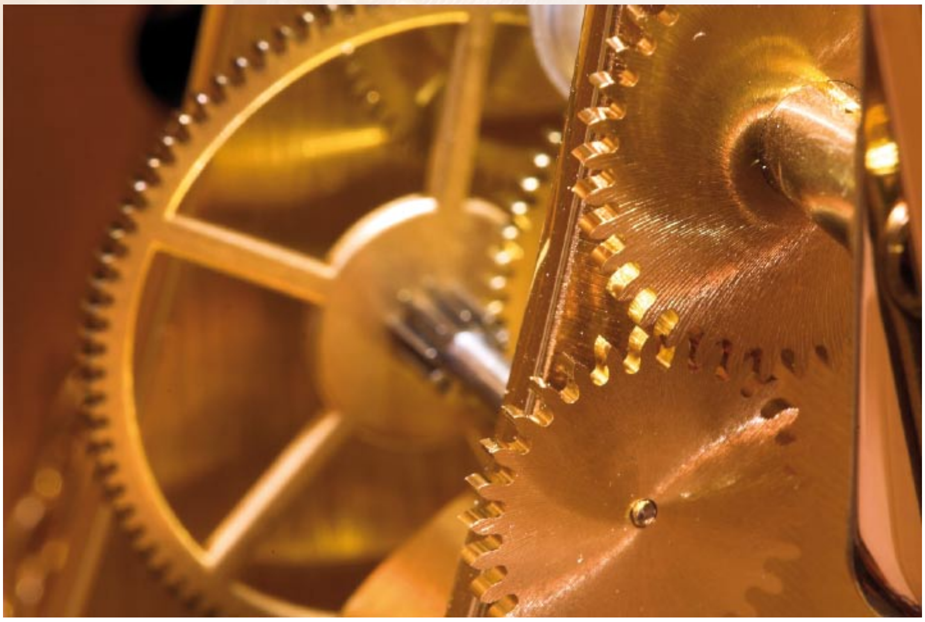
Precision out of Gold City

Methods for High-precision Optical Measurement

A combination of a high-resolution sensor system and precision mechanics is required for high-precision measurement of large, complex geometries. Depending on the task at hand, the optical properties of the measured objects, part handling and machine set-up, different measurement technologies need to be chosen. EHR, out of the "gold city" Pforzheim, is specialized in customized multi-sensor solutions for precision measurement machines.



The most important component in a precision-measurement machine is the sensor for data acquisition. Coordinate measurement machines (CMMs) generally use tactile i.e. contacting sensors or so-called test probes. However, non-contacting optical sensors are being used ever more frequently. The most commonly applied measurement principle in this case is laser triangulation. Tool presetters on the other hand are primarily based on telecentric measurement principles. Both processes are camera-based – images are captured and then analyzed. Therefore, the term used is image analysis or machine vision.

General view of the precision measurement machine for semi-automatic measurement of synchronizer rings

Other machine vision measurement methods are white light interferometry, stripe light projection, laser micrometers and confocal chromatic distance measurement sensors. With the EHR precision measurement machines, all these methods can be combined to create an overall solution.

Capturing Large Measurement Ranges

The disadvantage of all high-resolution measurement methods is their small measurement fields. Standard tool setting devices feature a telecentric measurement setup with measurement fields in the order of 1 cm². Laser line triangulation devices, which can achieve approx. 10 µm in resolution, have a measurement range of around 2 cm. Much the same applies to other sensors.

This means that it is possible to measure indexable inserts, drill bits, milling cutters and other tools with similarly small dimensions, but not components or tools that are a few decimeters in size. In order to capture large measurement ranges, mechanisms that can move the small measurement field of a high-precision sensor system to a sensing point are required. Since the positioning accuracy of mechanics alone is much too imprecise, this must be determined by an incremental travel measurement system. Only this combination can facilitate a comprehensive high-precision measurement system over large distances.

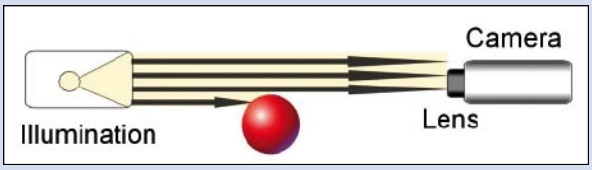
Control and Evaluation

The central element of any measurement system is the software that controls the various components. EHR generally uses one or more IPCs instead of a PLC. The basis for the control software is EHR's own system nucleus TIVIS, which is responsible for the following tasks:

- capturing the measurement values of various sensors or cameras,
- evaluating and interpreting the data,
- controlling the mechanics, incl. reading out the incremental position measurement,
- synchronization of all measurement data,
- machine vision,
- communication with superordinate control systems,
- communication with and/or control of robots or other mechanisms,

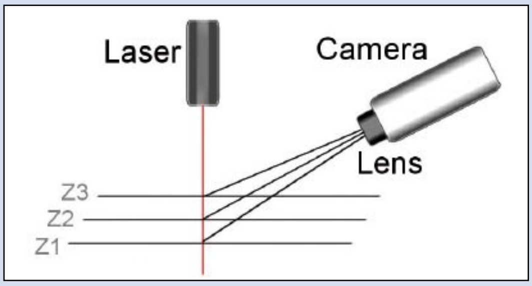
Optical Measurement Methods: Measurement Principles and Accuracies

Telecentricity



Telecentricity is taken to mean the direction of the principal ray parallel to the axis, i.e. an aperture angle of 0°, of lenses and illumination in general. The advantage of telecentric lenses is that the size of the objects in the telecentric range (this is roughly the depth of field range of the lens) does not change. Therefore, these lenses are freely used as measuring lenses, e.g. for tool pre-setters. In this case, telecentric illumination shines directly into a telecentric lens (with a common optical axis) and the object being measured is located between the two. The great advantage of this arrangement is that specular objects can also be measured because reflected rays are no longer imaged on the object. The disadvantage is that, firstly, only outer contours can be captured and, secondly , that the lens diameter is approx. twice as large as the image field or measurement range. The measurement accuracy largely depends on the size of the field of view, the resolution of the camera and the software-related sub-pixel interpolation. Typical tool pre-setters with a field of view of just 1 cm^2 and a 1 megapixel camera can achieve measurement accuracies of a few µm.

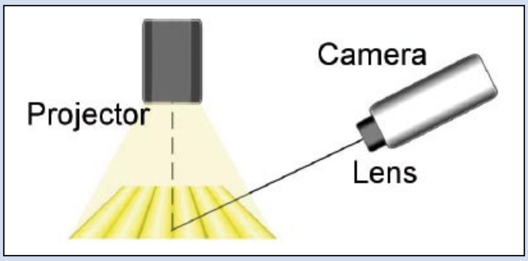
Laser Triangulation



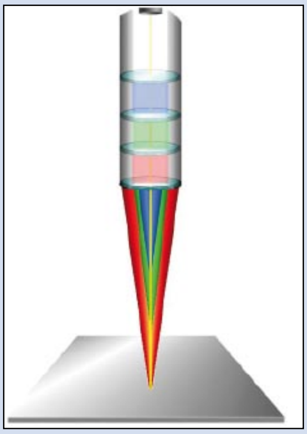
Laser triangulation refers to light section methods where, for example, a straight laser line is projected onto an object and captured at a particular angle (triangulation angle), by a camera. The deviation of the straightness of the laser line in the camera image provides a dimension for the object height along the line. A scan of several lines produces a depth image (surface profile) in X, Y and Z. The measurement accuracy largely depends on the length of the line and the camera resolution. With a line length of approx. 20 mm and a VGA resolution camera, the measurement accuracy is in the order of 10 µm. With the right software interpolation, the measurement repeatability achieved is then approx. 1 µm. Laser triangulation is a well-established method of measurement that is both robust and cost-effective. However, it is a scanning method so that either the sensor or the object being measured must be moved. Specular or semi-transparent surfaces can prove difficult (not „equable" in optical terms).

Stripe Light Projection

The stripe light projection is a triangulation method as well. Here many parallel lines are projected onto the object which are then captured at a particular angle by a camera and analyzed. A distinction is drawn between the Coded Light Approach (CLA: discrete light-dark lines that come closer together image by image; Gray code sequence) and the phase shift method (stripes with sinusoidal intensity modulation shifted laterally by quarter periods). In order to compute a depth image on the basis of this, several images must be taken with the changed stripe pattern. This method produces 3D data directly without a scanning device although a stripe projector is required. In this case too, the measurement accuracy largely depends on the size of the field of view and the camera resolution. With a FOV of approx. 1 cm^2 and a 1 megapixel camera, measurement accuracies of approx. 10 µm are typical.

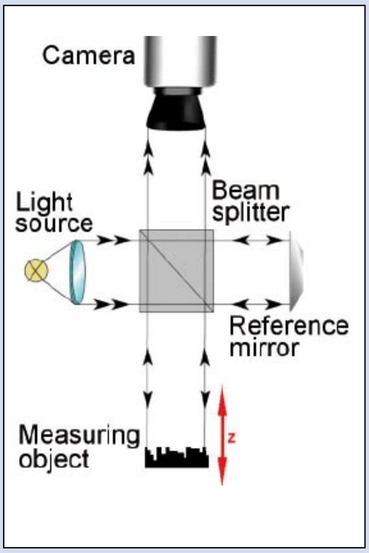


Confocal Chromatic Distance Measurement Sensors



With confocal chromatic distance measurement sensors the color error of lenses (chromatic aberration) is used by splitting white light when focusing on the measured object in such a way that in order to obtain a distance, only one color is imaged sharply. The color of the light scattered by the measuring point (diameter approx. 10–100 µm) is measured and assigned to a distance. This measurement method is extremely precise and produces measurement accuracies in the sub-micrometer range even with specular and transparent surfaces. As a result of the confocal arrangement of light source and detection optics, there is no shadowing as with triangulation measurement systems. One disadvantage is that so far this method of measurement can only be used selectively.

White Light Interferometer



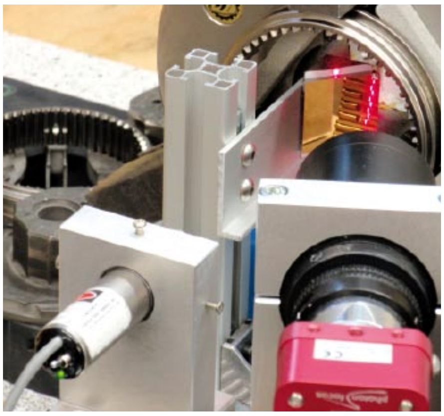
White light is guided to the object being measured through two channels. With certain heights, there are light superposition effects (interferences) which are captured by a camera. The distance is predetermined for these heights. All the heights of the object being measured are obtained as it is moved up and one image is registered each time. A depth image is then compiled from all the images. In the case of measurement fields of up to 25 cm^2, the measurement accuracy is in the sub-micrometer range. This is a scanning method with which several images are captured. One disadvantage is the rather large and cumbersome setup which is not particularly robust either.

- archiving of measured values or other data,
- password management,
- customer-specific tasks.

In order to evaluate the measured data, the company‘s in-house machine vision library has been integrated into TIVIS. The machine vision tools of the powerful Halcon library are also available.

Application-specific Choice of Measurement Technologies

Using the hardware and software basis described, various combinations have been compiled at EHR to create customer solutions. Crankshaft mills in particular provide a graphic illustration of precise µm measurement of large objects. Here the position of dozens of small indexable inserts must be measured and, where necessary, realigned. To do this, a stable arm was fitted to the z-axis of a tool presetter in such a way that the laser scanner is positioned centrally in the tool so that the individual indexable inserts can be moved precisely into position from there.



Prototype for internal measurement of a gear change sleeve with laser triangulation penetration optics

EHR also specializes in the measurement of internal part characteristics. The teeth of gear wheels, for example, are frequently measured tactile by „dislocation“ (over-pin dimension). Here, the penetration depth of a ball is measured between the tooth flanks. This process is costly because it is very time consuming. With the EHR algorithms, the gear wheels are „digitally dislocated“: A laser scanner captures its 3D contour into which balls of the same radius are then mathematically fitted. In this way, both measurement methods are directly comparable but with the great advantage that the latter measurement method can be automated and performed without the risk of human error.

Further measured values can also be obtained with the same measured data, e.g. parallelism and axial run-out of areas, heights, angles, diameters, roundness and other special component-related characteristics. This ensures fast, comprehensive quality assurance. Internal areas that are difficult to reach or which cannot be accessed using standard triangulation sensors are acquired with reflector (or prism) designs and separate camera-laser components.

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