# Polytec

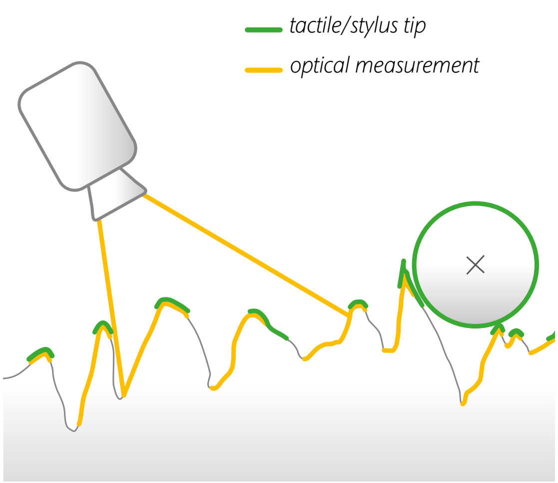
Technology benchmark

# Technology comparison in optical surface metrology

# Optical vs. tactile profiling

**Many engineering applications such as lubrication, friction reduction or polishing, in which the surface information is needed, require the characterization of the topography. And basically, there exist optical or tactile methods which can be applied to acquire spatial coordinates of a surface.**

From a general point of view, both methods need to have an access to the surface. As shown in the image, optical methods get data if they „see“ the surface and the „hidden“ points will not be acquired. In tactile methods surface data is acquired if there exist a „contact“ between stylus tip and surface, whereas the level of information is highly restricted by the diameter of the stylus.




Even industry has gained most of its experiences with tactile methods (mostly due to historical reasons), optical measurement technology has many advantages – no contact, areal and fast, higher information density, (the non-contact measurement also means that no deformation of the surface due to probing force), is therefore becoming more and more accepted worldwide.

Optical measurement technology is not only faster but also creates a digital image of the entire measuring object and therefore delivers more detailed quality information than tactile measurement technology.

Especially if higher data densities are required, tactile methods need significantly more time: Getting hundreds of measuring points on one surface can take a long time, sometimes several hours. Therefore, a complete inspection is not easily possible with tactile methods in production because of the time investment. To save time, the number of measuring points can be reduced, but this is at the expense of the data density. Here, the ratio of time investment and data density always has to be carefully weighed.

On the other hand optical areal measurement can provide a very high data density (in seconds) when this is required. But at the same time, this density can also be reduced for time challenging applications.

**Comparison of two techniques: contact and non-contact**

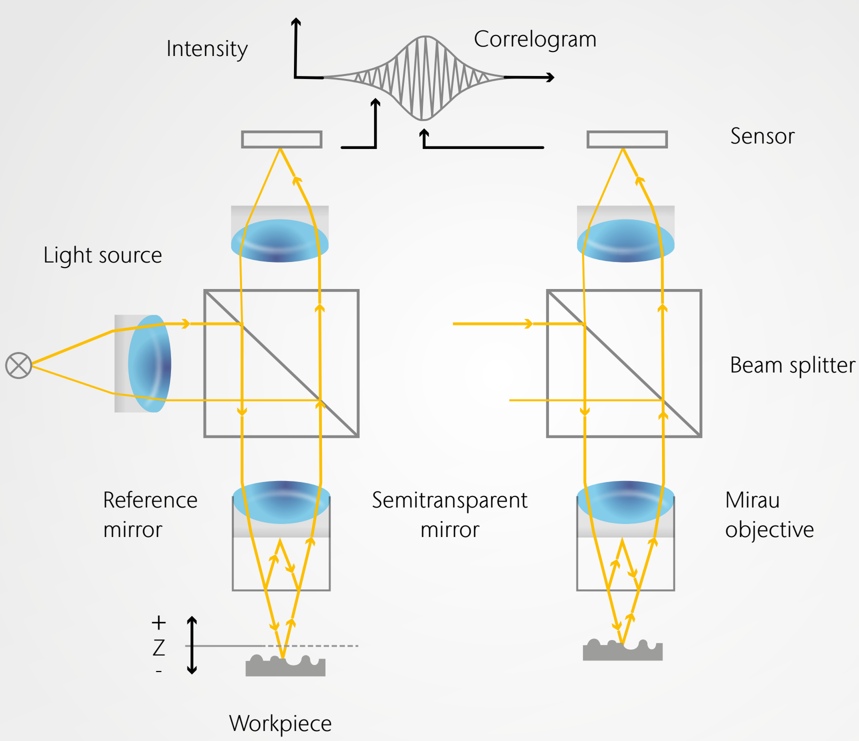
| | Optical | Tactile/Stylus |
|---|---|---|
| Non-contact, non-destructive | yes | no |
| Awareness of technology by all industries | limited | yes |
| Affordability by all users | limited | most |
| Suitable for highly sensitive surfaces (e.g. soft or fragile materials) | yes | no |
| Sensitivity to optical properties of surfaces (e.g. appearance or reflectivity) | yes | no |
| Quick visual representation of sample | yes | limited |
| Amount of data per unit of time | high | low |

# Optical methods – a brief overview

**For applications where tactile surface measurement techniques have limitations, non-contact optical instruments can offer great possibilities to overcome these shortcomings. Especially with the development of computing capability, these methods provide surface information quickly and with high resolution. There are four common principles which are mostly applied in industry.**

## 01 White-light interferometry (WLI)

**Representation of optical set-up (Mirau type)**

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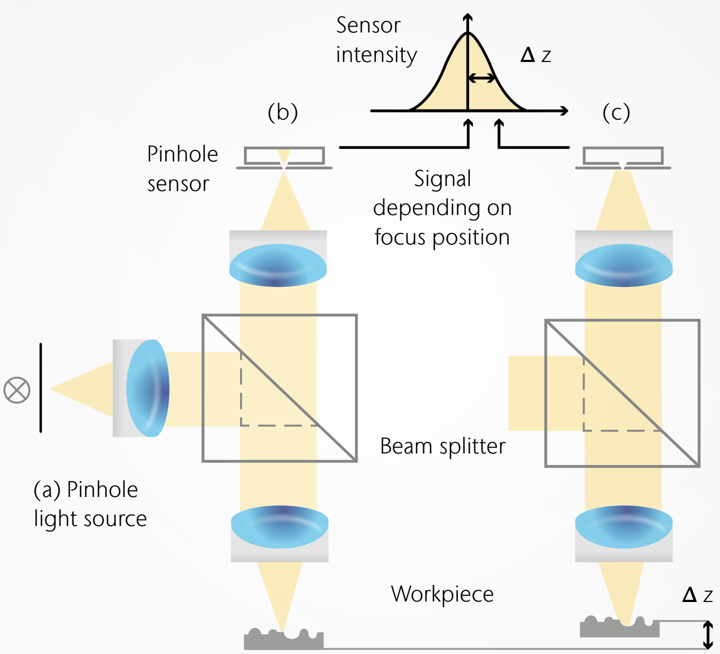
**Overview of white-light interferometry**

- Excellent vertical resolution independent on the objective
- Suitable for rough to smooth surfaces
- Large surface can be measured - without stitching

Due to its vertical resolution, **white-light interferometry** has been accepted as an important tool for the investigations of surface topography. In general with the help of special objectives (e.g. Mirau objective) an interferometric beam path is realised and this splits the light into two light paths. One of the beams reaches to the sample surface and the other to the reference mirror. The Mirau objective (or the sample as shown in figure) is driven by a precision stage along the optical axis. During its vertical movement, the intensity of the reflected light is detected for each pixel in the sensor. The maximum of intensity modulation in the interference correlogram occurs at a position where the distance (the beam path) to the measuring object is equal to the distance to the reference surface (mirror). This maximum is evaluated to get the height data of each point. Finally, the height data together with the corresponding lateral coordinates give the topography of the sample. Vertical resolution is independent of measurement field (field-of-view). Therefore even larger surfaces can be measured with nanometer vertical resolution without an additional need for stitching. Similar to the other optical techniques, the lateral resolution is determined by the objective magnification.

### Working principle of confocal microscopy



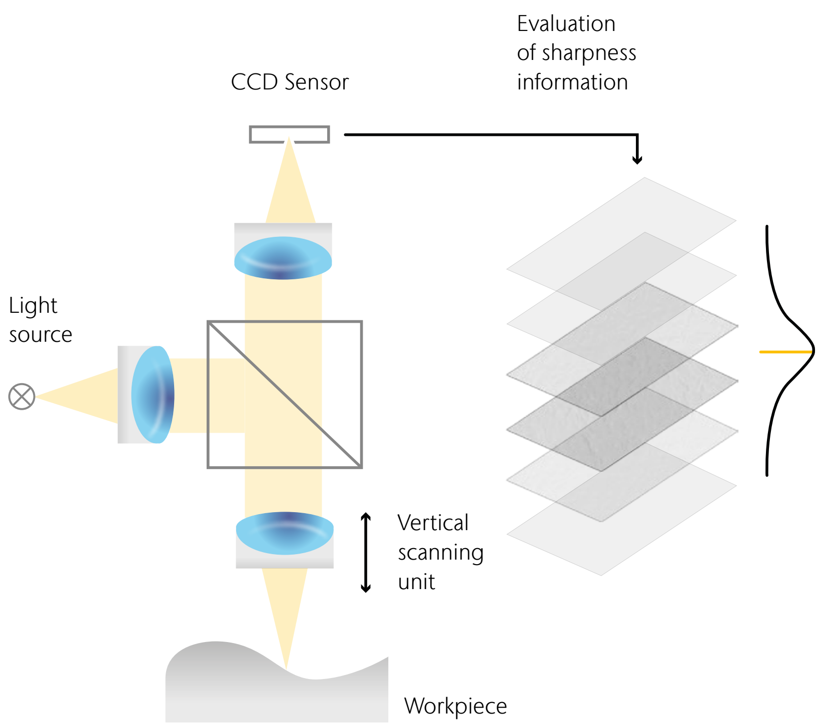

**Overview of confocal microscopy**

- Vertical and lateral resolution depend on the objective
- Surfaces with high slopes can be measured
- Objectives with high NA are available

Basically **confocal microscopy** is based on the combination of small depth of focus of optics with vertical movement to get surface data (height information). With the help of a pinhole the sample surface is illuminated in a restricted way and the reflected light is detected with an additional pinhole, which is also known as confocal aperture. Confocal aperture blocks the light that comes from the surface points which are out of focus. In other words, surface information is calculated only from the regions which are in focus. The signal which is detected during this vertical scanning is called axial response and maximum of this curve is used to locate the position when the surface point is in focus. By means of a vertical movement, optically sectioned images are generated in this way. Actually, it is a point- based method but for areal measurements, a larger number of light sources (points) are simultaneously applied and a CCD array is used to detect each signal. Vertical resolution depends on applied objective.

# 03 Focus variation

**Overview of focus variation**

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**Overview of focus variation**

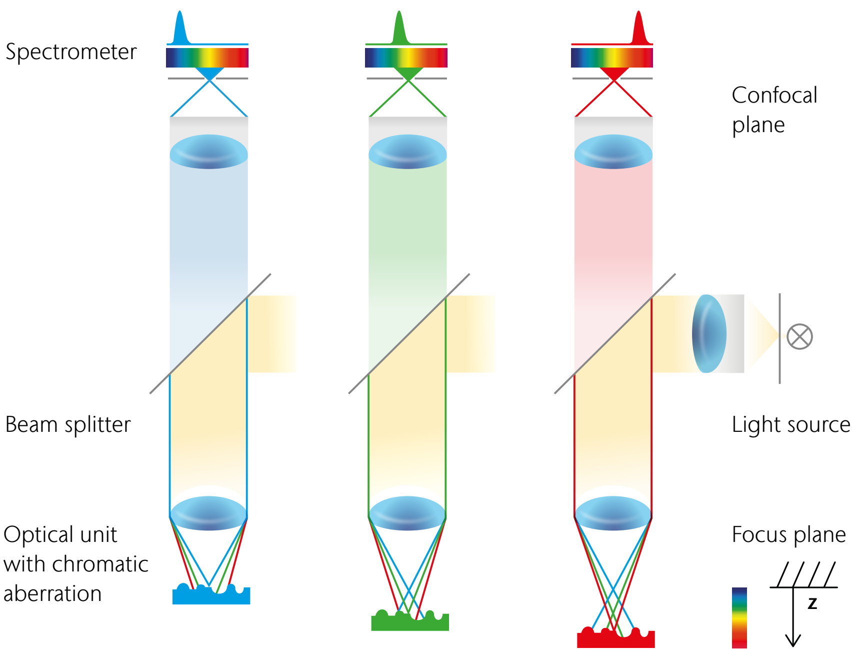
- Smooth/shiny surfaces are hard to measure
- Stitching is required to measure large areas
- Vertical and lateral resolution depend on the objective

The combination of small depth of focus of an optical system with a vertical scanning unit is the main idea of a **focus variation** system. The light coming from the source is directed to the workpiece and the reflected light is detected by the CCD sensor. Due to the small depth of field of optics, only a restricted region of surface is sharply captured. By means of vertical movement, the distance between objective and workpiece is varied and at each stage, images are continuously acquired. By this movement, each region is captured sharply. Algorithms convert the acquired data into 3D information of the surface. Both lateral and vertical resolution depend on the applied objective.

Measurement performance highly depend on geometrical surface characteristics: Measurement of surfaces with high slopes is possible but measurement of smooth or shiny surfaces can be a challenge for focus variation. In order to get correct values, investigated surfaces should have textures on them.

# 04 Chromatic confocal sensor

**Working principle of chromatic confocal sensor**

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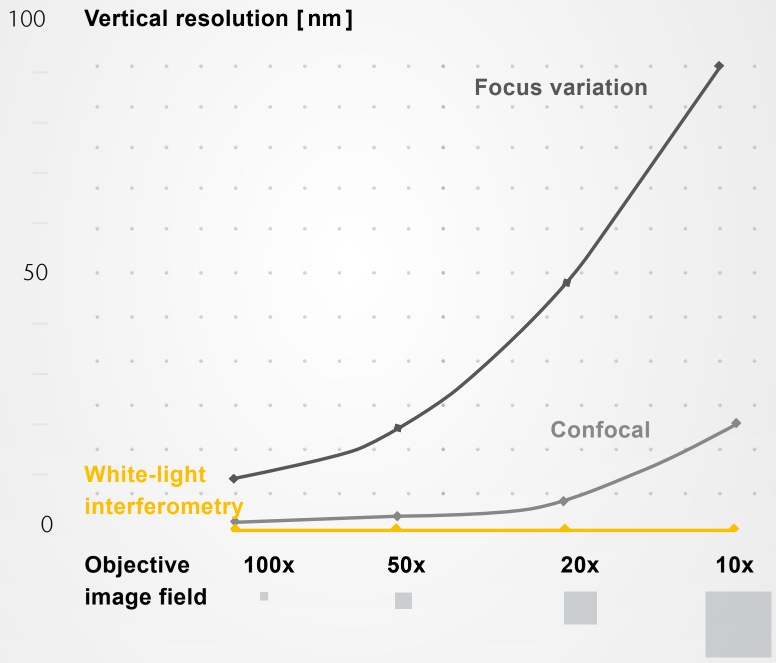
**Overview of chromatic confocal sensor**

- Point/line- based data acquisition
- Time consuming for large areas
- Limited vertical resolution
- no need for z-scan

As an optical method, **chromatic confocal** probing is most similar to stylus profilers (tactile methods). Surface data is acquired by scanning a point sensor with the help of a laterally translated stage and, as with tactile methods, the length of the scanned profile is only limited by the displacement of the stage. Such a configuration allows for tracing complex shapes and even circular profiles can be measured. It is limited for time-critical areal measurements  since it needs stitching. And also the vertical scanning range in vertical direction can be a limitation for some applications. However, it does not require a vertical scanning unit, which makes it possible to have a completely static measuring sensor with this technology.

White-light is separated into different colored focal points and focused on the sample. The intensity of the reflected light is evaluated with a spectrometer. As the wavelength which is focused on the sample surface has the maximum intensity, the distance between the sensor and the sample surface can be determined by comparison tables.




**Resolution independent of field of view**

In the mentioned areal-based optical surface metrology methods, lateral resolution depends on the chosen objective. But if the vertical resolution is considered, white-light interferometry is the only one where resolution does not depend on the objective.

**With other words, white-light interferometer provides the same resolution independent of field-of-view.**

**Comparison of different optical techniques with respect to their measuring capabilities**

| | White-light interferometry | Confocal microscopy | Focus variation | Chromatic confocal sensor |
|---|---|---|---|---|
| Vertical resolution | Excellent, does not depend on objective | Good, depends on objective | Good, depends on objective | Good, depends on z measuring range |
| Lateral resolution | Good, depends on objective | Good, depends on objective | Good, depends on objective | Moderate, depends on the spot size |
| Data acquisition | Area-based | Area-based | Area-based | Point or line based |
| Ability to measure large areas | Even without stitching possible | Requires stitching | Requires stitching. Not very good on very flat surfaces | Very time consuming |
| Ability to measure smooth surfaces (Sa~1nm) | Excellent | Moderate | Poor. Needs surface contrast/texture | Moderate |
| Ability to measure rough surfaces (Sa~1µm) | Good. Even larger surfaces can be measured | Good | Good | Good |
| Film thickness measurement (in µm level) | Possible (in some cases even under µm) | Possible | Difficult. Smooth surfaces are challenging | Possible |

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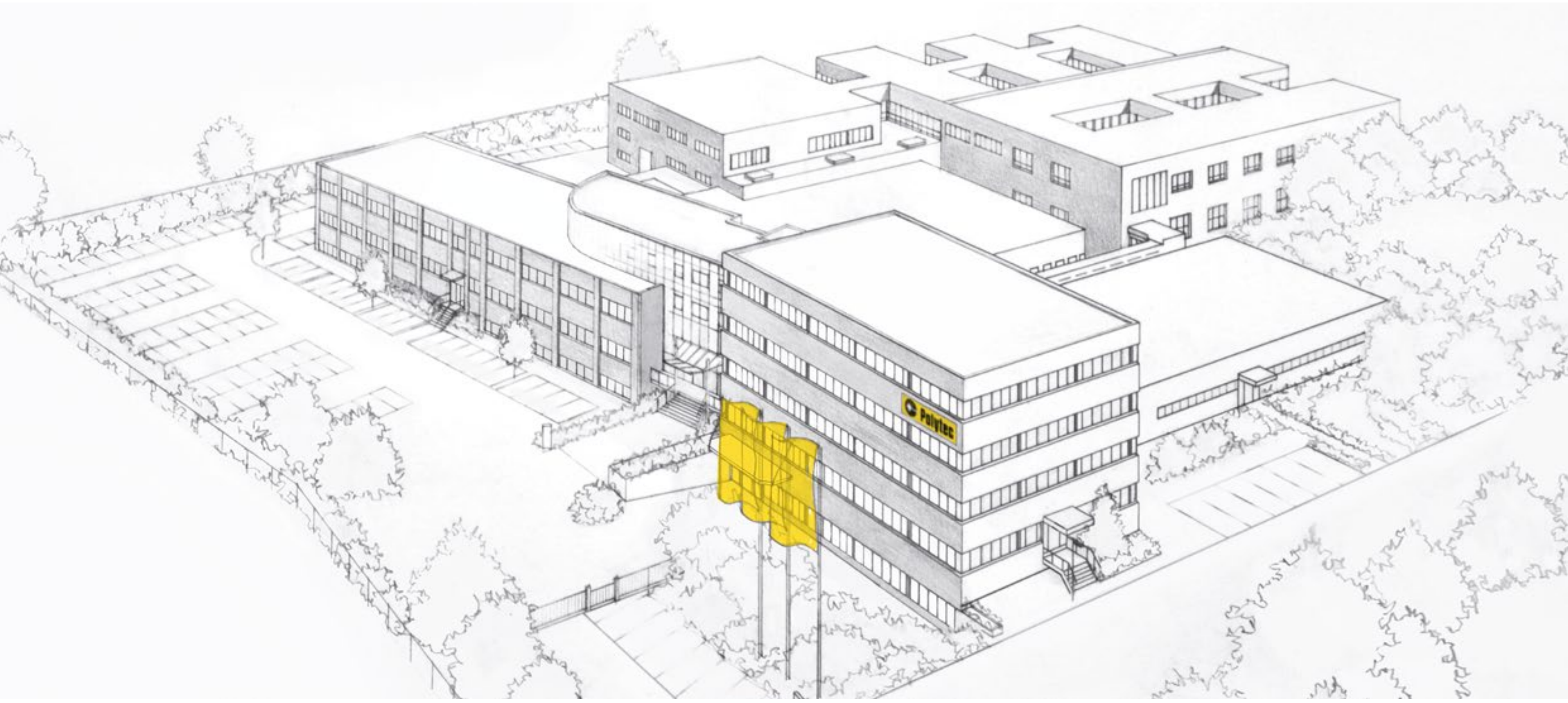


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