Optical surface inspection for glossy and transparent components

Factors that significantly influence feasibility and data quality

ISRA VISION
Part of Atlas Copco Group

ISRA VISION's optical surface inspection technology **for glossy and transparent components** is based on cutting-edge sensor technology. Depending on the configuration of the inspection solution, one or more cameras capture the **reflection of a projected stripe or stripe pattern**. Analyzing this reflection provides precise information about surface defects, warping or irregularities.

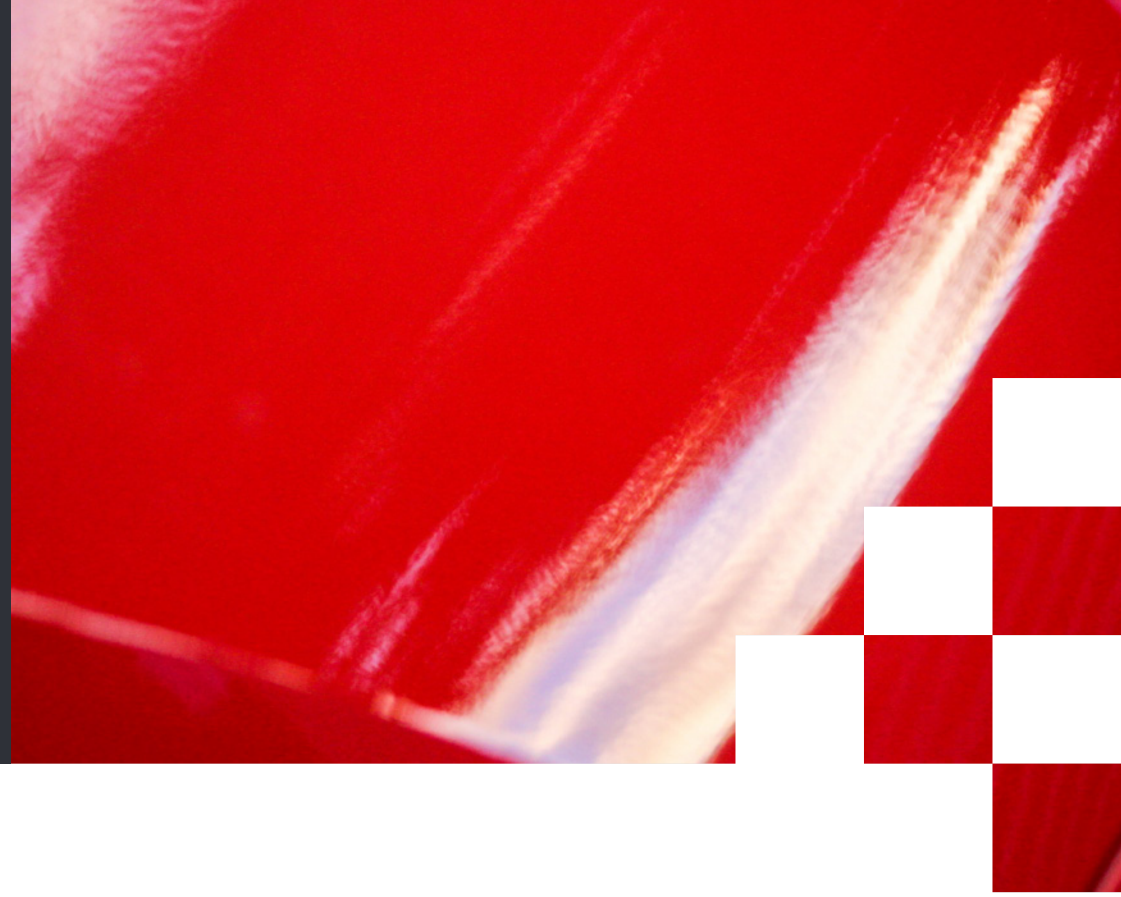
The **quality of the acquired data** and the feasibility of the inspection depend significantly on various influencing factors. We explain which parameters play a role in the following sections. Defects, required accuracy and cycle time also influence automatic surface inspection.

Factors

Component	Environment	Requirement
Surface	Contamination	Defects
Size	Transport mode	Accuracy
Geometry	Ambient light	Cycle time

Surface

For measurement methods based on targeted reflections, such as deflectometry, the nature of the component surface is of central importance as it directly affects the effectiveness and reliability of the measurement method. Colors, on the other hand, only play an indirect role in data quality. These methods produce particularly good results on mirror-like or highly reflective surfaces. With matte or transparent materials, light is scattered or refracted, so an adapted setup may be required.



Surface type:

Glossy
The pattern is clear and sharp – very good data quality.

Transparent
Very good data quality with the appropriate setup.

Matte
Scatters light significantly, causing the pattern to become diffuse or invisible and limiting data quality.

Textured
Local structures, such as grooves, embossing, or textures, can distort or scatter the pattern, making evaluation more difficult and limiting data quality in some cases.

Colors indirectly affect data quality:

Dark colors absorb more light → better contrast leads to better data quality

Light colors absorb less light → lower contrast leads to reduced data quality

Metallic colors (e.g., metallic paints) can sometimes reflect light well, but this depends on the surface texture and coating.

Since the optical behavior of a material depends heavily on its surface, and since feasibility cannot always be predicted, it is advisable to conduct practical tests using typical components. These tests allow one to determine early on whether the chosen measurement method is suitable.

Size

In optical surface inspection, the size of the component being inspected is crucial. It significantly influences key parameters such as measurement fields and resolution, system design and measurement geometry, measurement time and data volume, calibration, and accuracy. While small components can often be inspected with high precision and relatively little effort, large components place special demands on the inspection system. The respective challenges and special features are explained below.

Measurement duration and data volume

Small components

- Require a small measurement field that can be easily covered by the camera and light source.
- Even relatively low resolution is sufficient to achieve accurate results.
- Good detection of even small defects or distortions.

Large components (approx. 300 × 200 mm^2 and larger)

- Require either:
  - a very large measurement field
  - or segmented measurement

System Configuration and Measurement Geometry

- Large components often require movable systems, such as robots or linear axes, or multiple cameras/projectors, to capture the entire object.
- Due to the angle dependence of reflection (i.e., incident angle equals reflected angle), not every region is equally visible on curved or very large surfaces.
- With very high curvature values, the pattern may be reflected at angles that are too shallow. This results in weak or distorted signals (see also “Component geometry”).

Measurement duration and data volume

- The measurement duration increases with the size of the component when taking multiple partial scans.
- Parallel scans reduce the total time but require greater computing power.
- A larger data volume means greater storage requirements and more computational effort to analyze the partial scans.

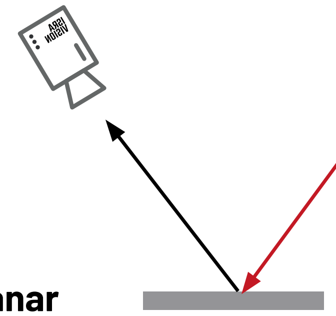
Calibration and accuracy

- Due to the nature of the process, achievable measurement uncertainty increases with increasing measurement volume.
- Precise measurements over large areas require a stable mechanical structure and effective environmental monitoring (e.g., temperature and vibration).

	Small components	Large components (from approx. 300 × 200 mm^2)
Measuring field size and resolution	Small measuring field, good coverage, high resolution per area	Large measuring field required, loss of resolution or segmented measurement
Setup and measurement geometry	Compact, stationary system usually sufficient	Larger measuring system or robot required
Measurement duration and data volume	Often shorter measurement times, low data volume	Longer measurement times with several partial recordings, higher data volume and storage and computation demand
Optical calibration and accuracy	Well controllable, long recalibration intervals, simple calibration	Higher requirements for calibration and stability due to large volumes and environmental factors (e.g., temperature changes)

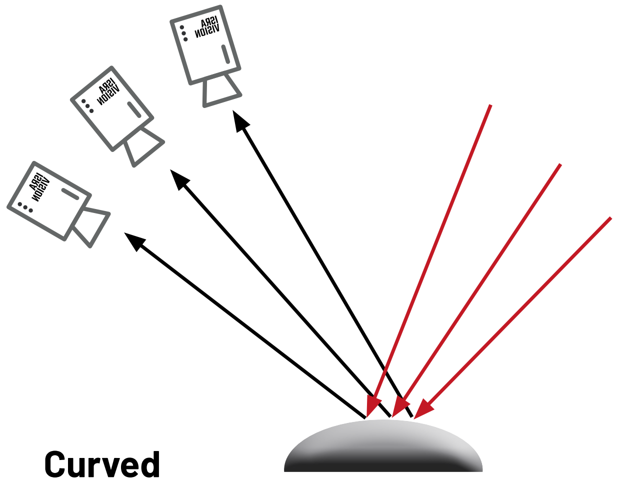
Geometry

In deflectometry, measurements are based on the law of reflection, which states that the **angle of incidence is equal to the angle of reflection**. In order for a light beam to be reflected from the surface to the camera, the camera must be positioned precisely at the point at which the surface reflects the light. Only then can the reflected pattern be correctly detected and analyzed.



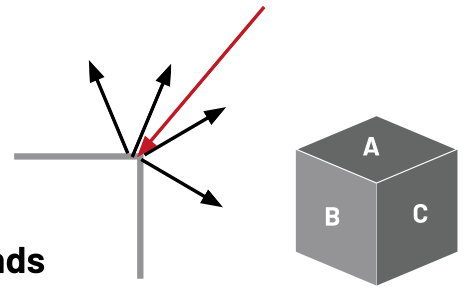
Planar

Flat or slightly curved surfaces are easy to measure.



Curved

Strongly curved or free-form geometries (e.g., spheres and lenses) reflect light over a wider solid angle. This is why multiple cameras are often used.



Edges and bends

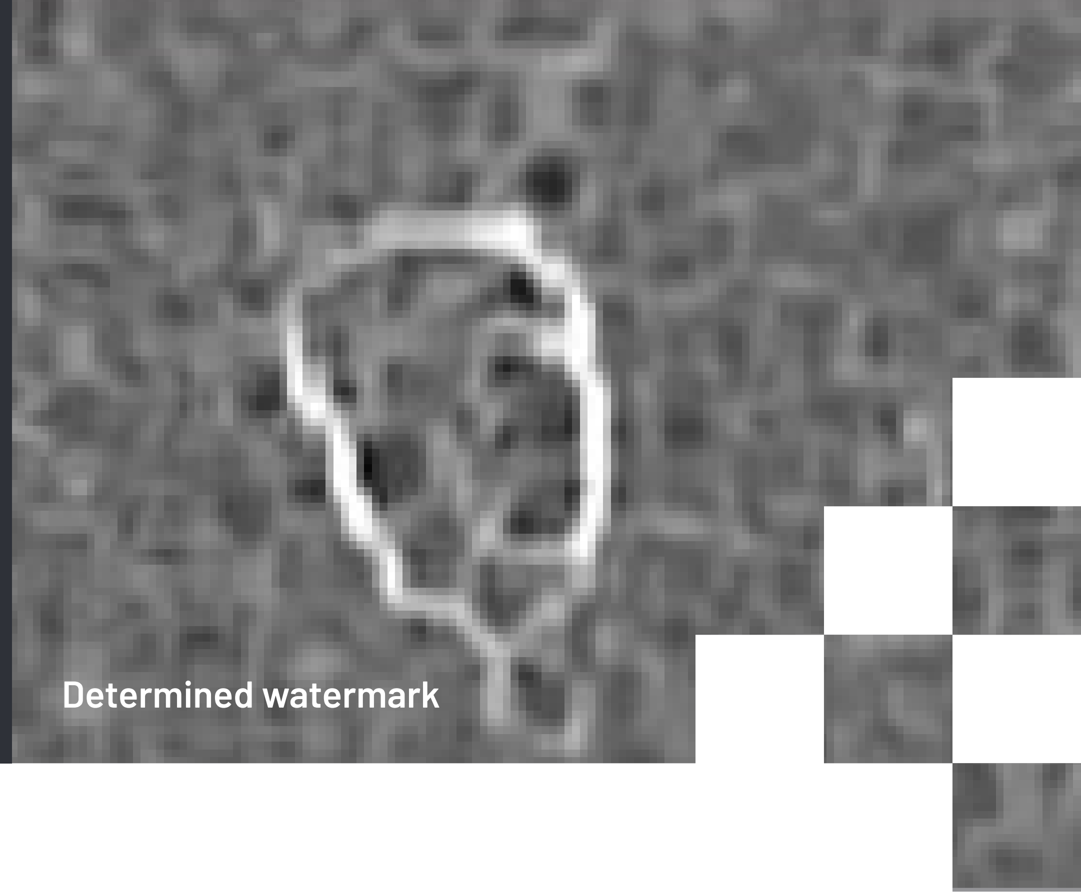
If there is a sharp edge or bend in the surface, the angle of reflection changes abruptly. In such cases, the light is no longer reflected toward the camera but in a different direction, often outside the camera's field of view.

While the edge itself cannot be measured, edge defects such as chipping can be detected by fully examining and evaluating the adjacent surfaces.

Components with complex, free-form geometries often need to be captured from various angles, so a robot-assisted system is usually the best option for inspecting them. Hidden geometries (e.g., undercuts and recesses) cannot lie in the reflection path, so measurement is not possible.

Contamination

Clean surfaces are the foundation for reliable image processing. While certain types of contamination with distinct characteristics—such as shape or size, for example lint or water spots—can be detected, classified, and in some cases filtered out without triggering a "NG" result, this requires that they can be clearly distinguished from actual defects. Additionally, this extra processing step may increase evaluation time.



Dust, dirt, or deposits on the component surface interfere with optical reflection:

Typical effects:

Diffuse reflection instead of specular reflection:
The pattern becomes blurred or distorted.

Light absorption at soiled areas:
Measurement gaps or misinterpretations.

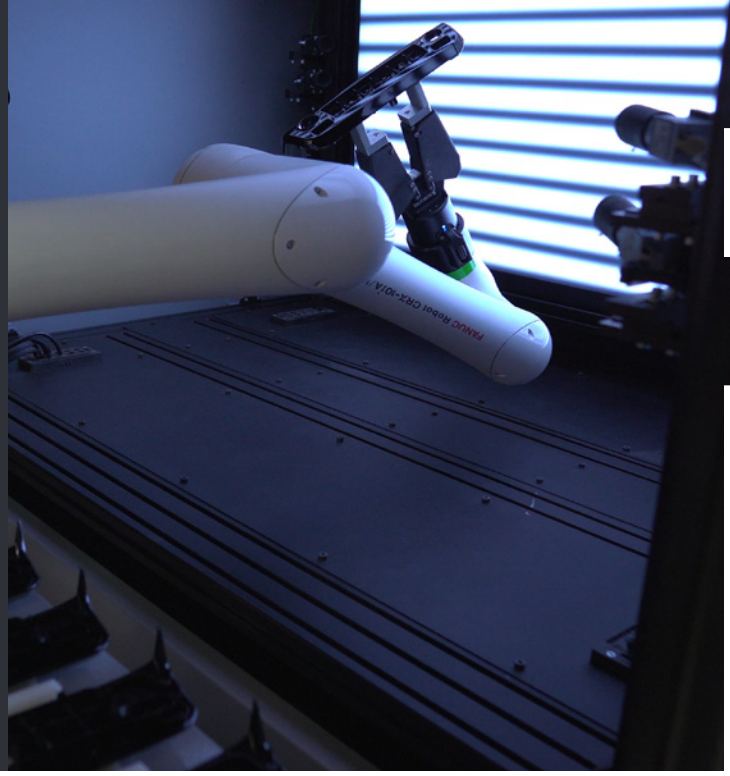
False-positive defects:
Dust is detected as a scratch or dent.

Consequences:

- Reduced data quality
- Difficult defect detection results in longer evaluation times
- Misinterpretation during evaluation leads to increased scrap.

Transport mode / positioning

The way a component is moved through the measurement system (or the measurement system over the component) has a direct impact on the stability of the image capture and, consequently, on data quality. Depending on the system, vibrations, positional deviations, or inaccurate positioning can result in blurry images, image distortion, or incorrect evaluations. Comparing different transport systems illustrates how various designs affect performance.



Transport system	Description	Advantages	Disadvantages
Conveyor belt (inline)	Components move continuously across a belt, e.g., in production lines.	Good for mass production; fully automatable; high throughput	Stop or removal required for precise measurement
Robot-guided	**Sensor** is guided by the robot to the measurement position or moved over the component. Or: **Component** is guided by robot.	Flexible component geometries; precise positioning possible	Programming effort; vibrations
Manual recording	Component is placed manually in a defined position.	Simple & fast; good for lab or single parts	Handling errors possible; less suitable for high volumes
Rotation (e.g., turntable)	Component is rotated between individual measurements; combined with conveyor or manual.	Good for mass production; fully automatable; low space requirement	Only for certain geometries

Ambient light

Ambient light (i.e., **unwanted external light**) can affect data quality in deflectometric surface measurement, since the method relies on the precise analysis of reflected patterns. Ambient light can distort the measurement result.

Possible effects:

- **Overlapping of the measurement pattern:**
  The projected pattern becomes "blurred" or overexposed.

- **Loss of contrast:**
  Less distinct details, poorer edge detection.

- **Spurious reflections:**
  External light sources are also reflected off the surface, causing false readings.

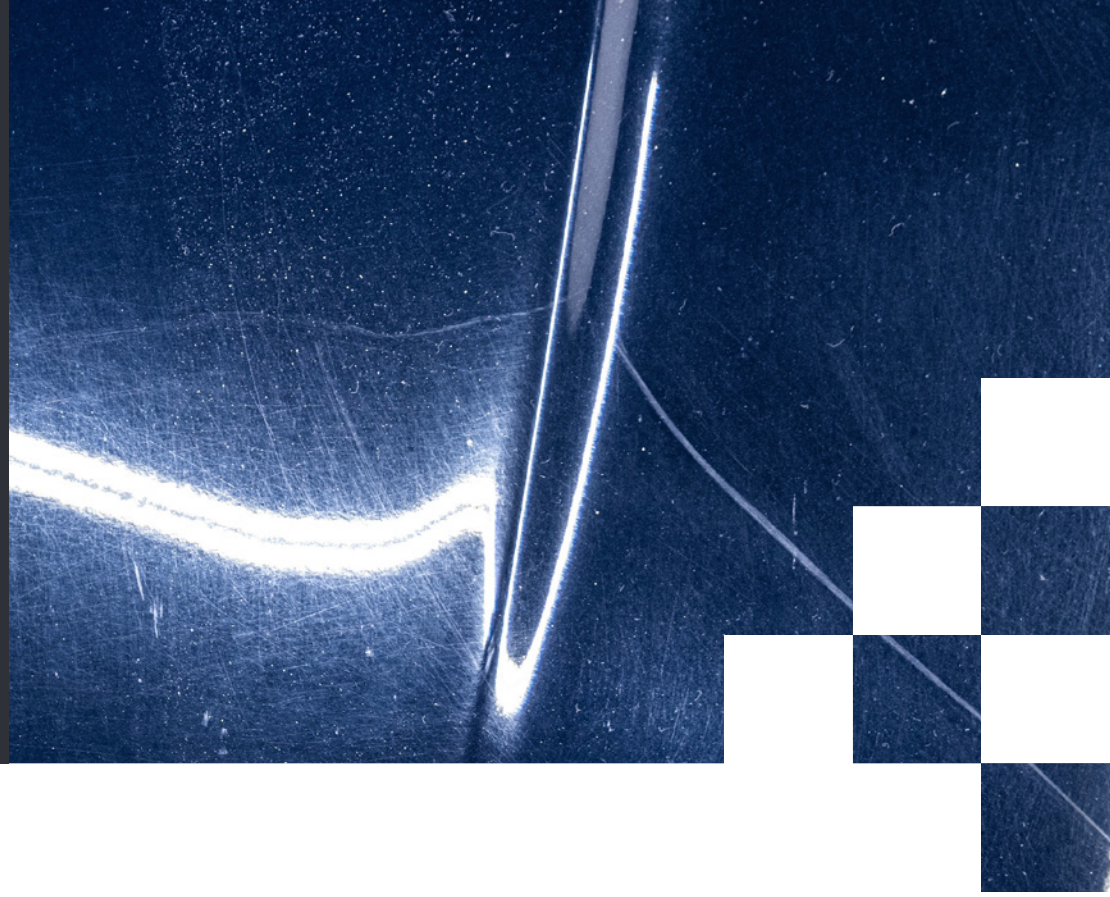
- **Flicker effects**
  caused by fluctuating ambient light intensity (e.g., from window light or unstable LED environments) – negatively impacts repeatability and increases noise in the data.

Solution:

- Optimized device design for low susceptibility to interference
- Synchronized exposure times
- Stable lighting conditions

Defects

A key objective of deflectometric measurement is reliably detecting defects. These defects include **scratches, dents, waviness, inclusions, and deformations** — that is, any features that alter the reflected image pattern locally. The challenge: Defects vary widely in shape, size, and depth, and are often difficult to distinguish from acceptable tolerances or harmless structures. Therefore, the accuracy of detection depends heavily on system resolution, evaluation logic, and inspection strategy.



The table shows which typical defects can be detected.

Defect	Description	Detectability
Chipping	Chipping at edges or surfaces; often occurs on brittle materials or mechanical stress.	Distinct reflection pattern due to abrupt geometry change
Crack	Fine to coarse cracks; may be surface-level or deep and run irregularly.	Depending on width and depth; fine cracks harder to detect
Dent	Locally indented area without material loss; caused by mechanical impact or thermal changes.	Visible due to local curvature change
Inclusion	Foreign body or material irregularity under or in the surface.	If under the surface: little influence; if surface affected: clearly visible
Sink marks	Flat, soft depressions due to material shrinkage or uneven cooling.	Detectable as large-scale shape deviation
Flow lines	Linear structures from material flow during processing.	Medium to difficult due to small geometric change
Shape deviations	Large systematic deviations from nominal geometry.	Deviation strength clearly measurable; ideal for deflectometry
Scratches	Linear surface damage with material removal; caused by faulty handling or tools.	Linear disturbance highly visible
Paint runs	Droplet or flow structures in coatings due to uneven application.	Detectable if affecting surface shape

Defect	Description	Detectability
Orange peel	Fine-grained irregular structure resembling orange peel.	Regular microstructure produces stripe pattern
Pinholes	Small point-like indentations caused by trapped gas or impurities.	Depending on size
Streaks	Striped discolorations from uneven material distribution.	Visible with sufficient contrast/geometric change
Read-throughs	Visible underlying structures due to shrinkage or stresses.	Macroscopic shape change clearly visible

Limitations

Deflectometry is a precise method for detecting changes in brightness, reflectance, and geometric surface deviations, especially on reflective or glossy surfaces. However, certain defects cannot be detected using this method, or can only be detected to a limited extent.

Defect type	Reason for limited detection
Color deviations	No geometric change—color/pigment differences do not affect reflection.
Transparent inclusions	If no surface deformation: invisible for opaque materials; transmission works for transparent materials.
Subsurface defects	Deflectometry captures only surface topography.
Micro-pores below resolution	Too small to detect.
Sub-micrometer roughness	High-frequency microstructures may be filtered out.
Edge areas	Defects near edges are less reliably detected.
Shadowing	Defects on hidden or non-reflective areas cannot be detected.

Accuracy

In the context of surface inspection, accuracy refers to an inspection system's ability to correctly, completely, and precisely detect and classify defects. Several aspects can be distinguished in this regard.

1. Detection rate

Ideally, an inspection system would detect 100% of all relevant defects. The detection rate is the proportion of defects that are correctly detected by the system. Example: If a system detects 95 out of 100 actual defects, its detection rate is 95%

2. Measurement accuracy (metric precision)

The system's ability to correctly measure the exact size or depth of a surface defect. Example: A system detects that a scratch is 2.3 mm long, rather than „approximately 2 mm."

3. Classification

How accurately are the detected defects assigned to the correct type? (e.g., scratch vs. bubble). Modern image processing systems rely on artificial intelligence (AI) and neural networks for classification.

4. Localization

Localization describes how precisely a defect's position on the surface can be identified. This is essential for automated rework or precise laser marking

5. Repeatability

The system consistently detects the same error multiple times, for example over several runs.

Conclusion:
The accuracy of surface inspections depends not only on whether defects are detected, but also on how reliably, precisely, and consistently they are identified in terms of type, location, and severity.

Side note:
Detection quality in surface inspection

Three key metrics are crucial for evaluating detection quality:

True Positive (T_p):	Correctly detected defects
False Positive (F_p):	Incorrectly detected (non-existent) defects
False Negative (F_n):	Overlooked, actually existing defects

Two metrics summarize these values:
Hit Rate (Recall): Indicates how many of the actual defects were detected:

$$\text{Recall} = \frac{T_p}{T_p + F_n}$$

Precision Value Indicates how many of the reported defects actually exist:

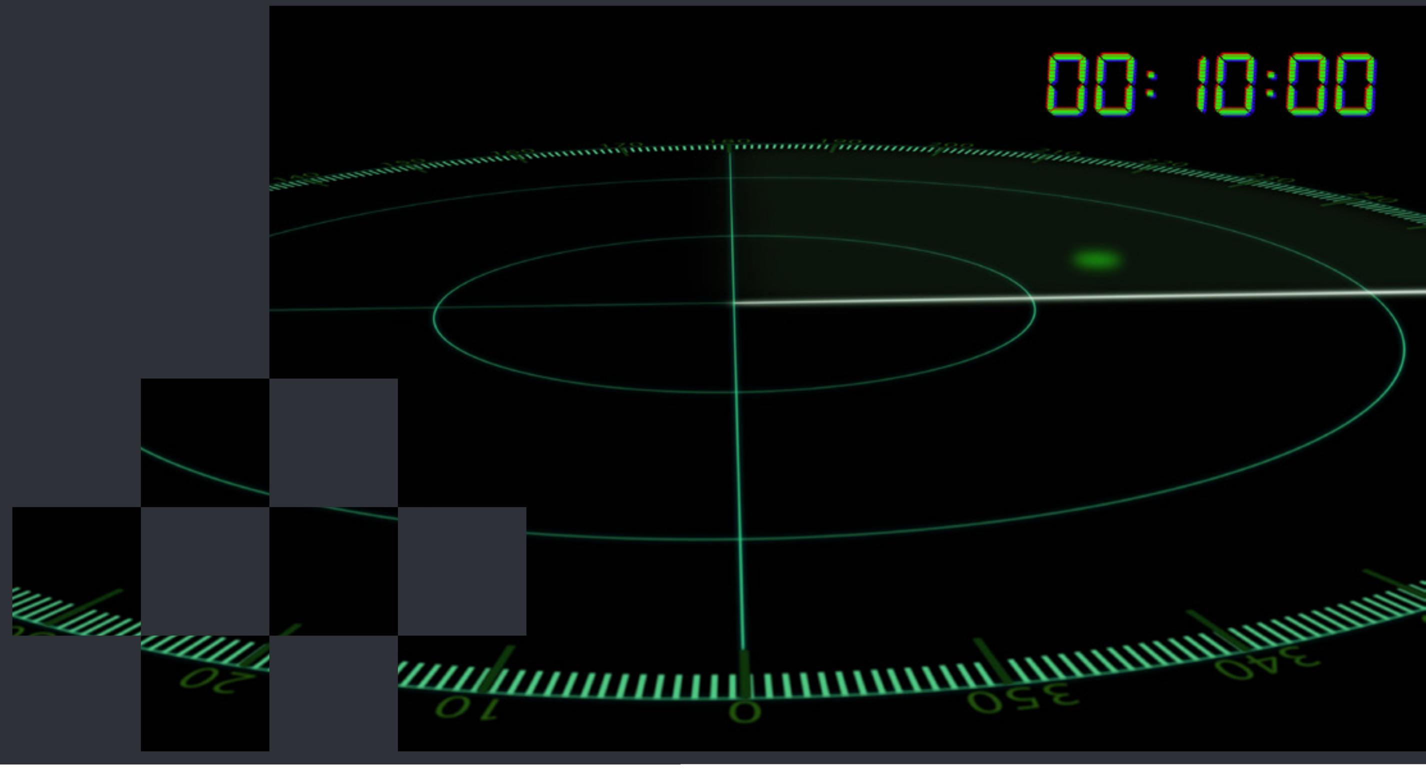
$$\text{Precision} = \frac{T_p}{T_p + F_p}$$

The goal is to bring recall and precision as close to 1 as possible — that is, to achieve a high detection rate while keeping the false positive rate low.

Requirement

Cycle time

The shorter the cycle time, the greater the **demands on the optics, hardware, and software**. Achieving reliable measurement results at high throughput rates requires high light output, high-speed cameras, powerful computing technology, and optimized algorithms, including parallel processing.



Challenges for image processing

Shorter cycle times mean less processing time per image, which requires more computing power. In systems not optimized for high cycle times, image resolution is often reduced, or the evaluation is simplified, to compensate. This can lead to reduced inspection accuracy when smaller defects can no longer be reliably detected, for example. Modern solutions avoid such compromises through targeted system design.

Aspect	Short cycle time (Fast production, shorter measurement time; analysis time depends on computing capacity)	Longer cycle time (more time per component)
Exposure time	Short exposure – less light – lower contrast	Optimal illumination – high pattern quality
Number of recordings	Minimized (e.g., one perspective)	Multiple viewing angles possible
Evaluation time	Optimized algorithms or more compute needed	More complex analysis possible
Resolution/details	Potentially reduced; small defects may be missed	Fine structures and micro-damage visible
Measurement reliability	Lower – risk of false negatives	Higher

The performance of an optical inspection system depends heavily on the environment and the components being inspected. With our feasibility check, you'll receive an initial assessment of your project.
Take the next step toward automated quality control by using our feasibility check now.

Feasibility check

Feel free to contact us for a personalized consultation!

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