CAD-Driven Robotic Inspection for Surface Analysis and Geometric Metrology

Merijn Vangilbergen, **Sina Ditzel**, Abdellatif Bey-Temsamani

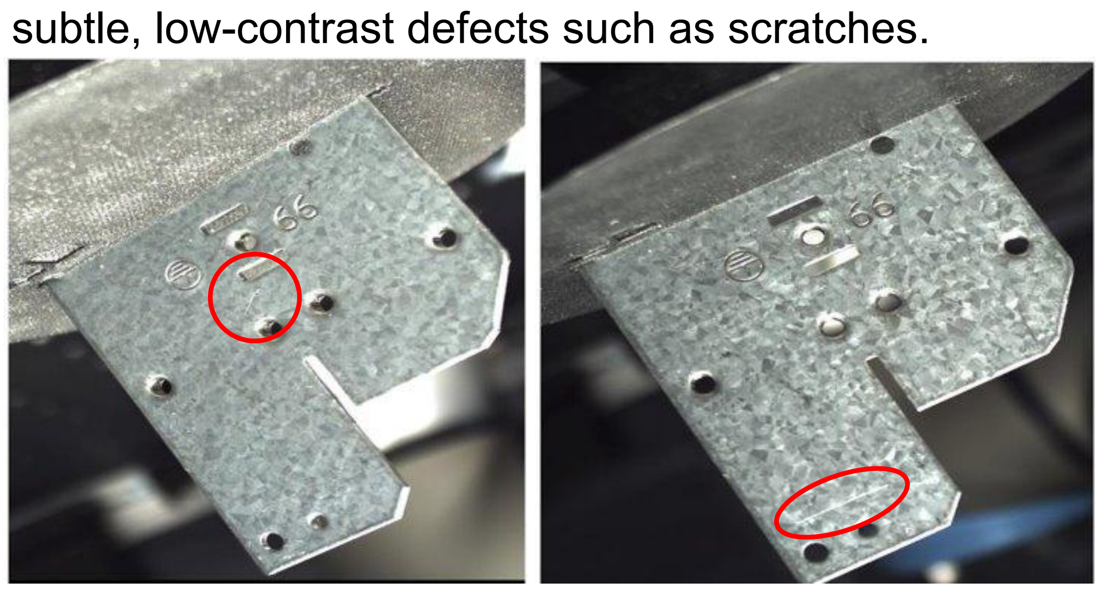
Goal

To develop a robotic inspection system for flexible and fully automated quality control of parts, meaning either robust detection of surface defects or geometrical dimensioning without markers.

Motivation

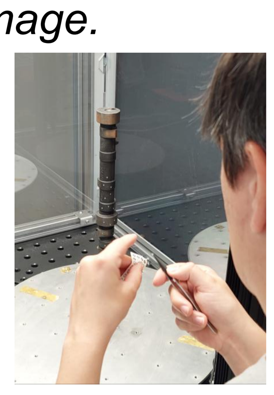
In today's competitive manufacturing landscape, the demand for fast and accurate quality inspection is rapidly increasing. The synergy between a visual sensor and a robot allows for automated inspection, but manufacturers are confronted with challenges.

• Scratch detection (2D). It takes analysis from multiple viewpoints using different lighting conditions to detect subtle, low-contrast defects such as scratches.



This plate was recorded from several viewpoints. Not all defects can be seen on one image.

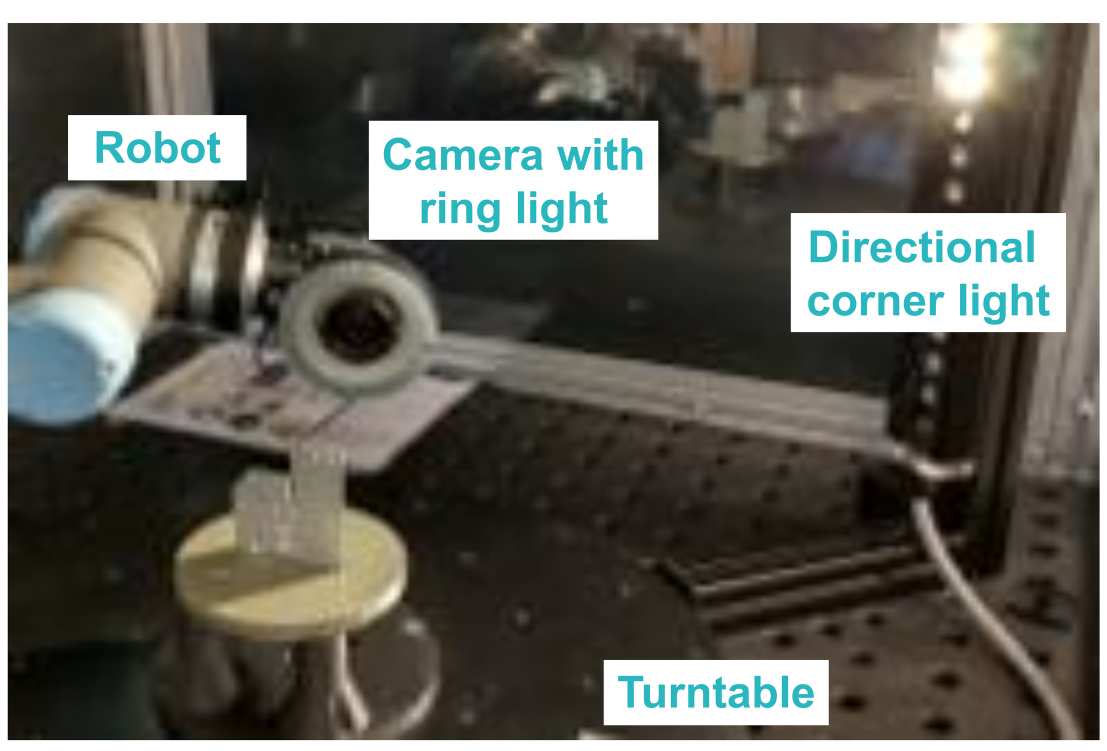
• Geometric dimensioning (3D). State-of-the-art 3D sensors require physical markers as reference points for data fusion. The application and removal of these markers is a repetitive job for a human operator.



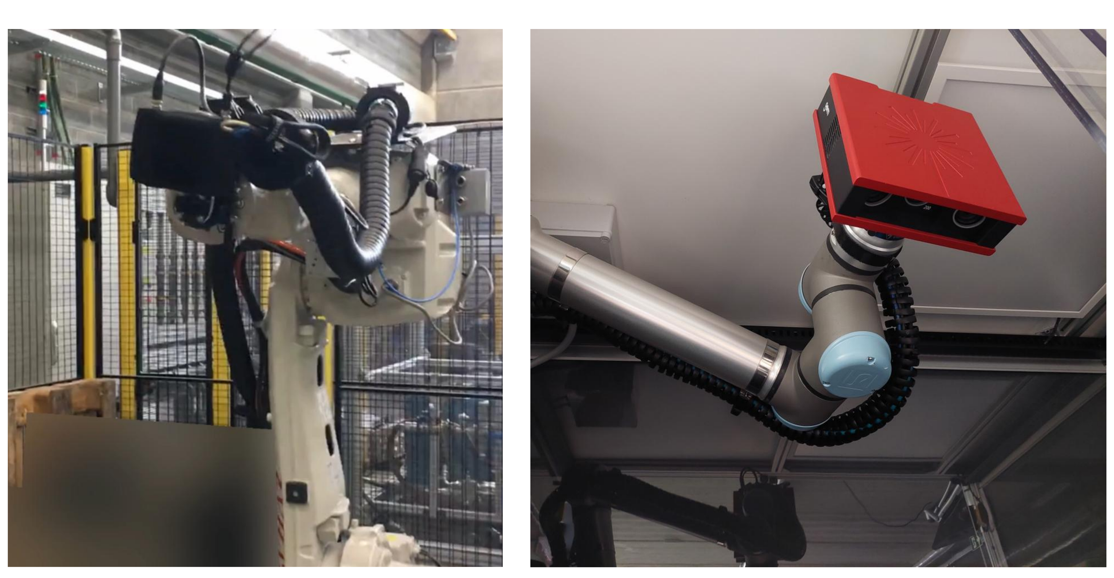
• The inspection of a part may be automated, but the initial set-up typically requires manual definition of the inspection plan. This time-consuming job needs to be done for every new part, which is then replicated for subsequent identical parts.

Approach - Hardware

The system integrates a robot with optional support for a rotary table, enabling access to all visible surfaces of the part. Sensors can be easily exchanged, supporting multiple 3D scanners and high-resolution RGB cameras.



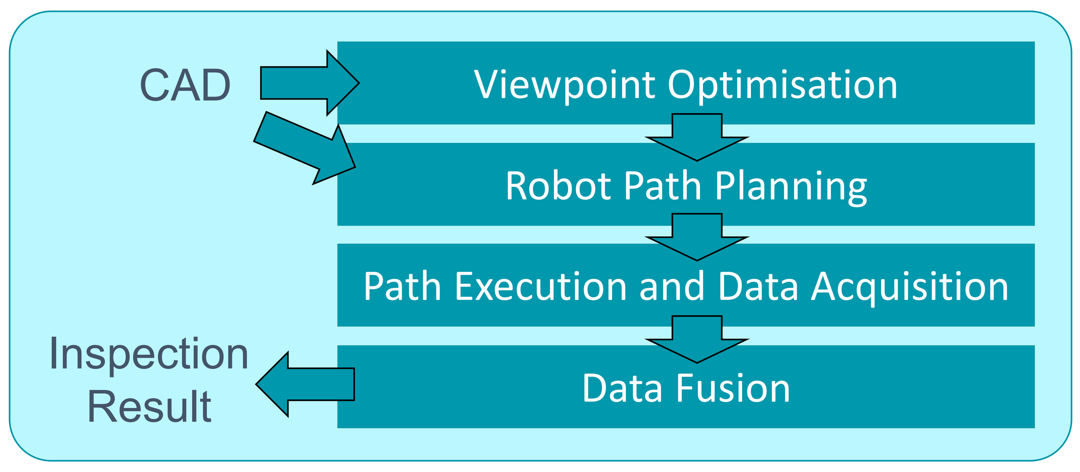
Active Vision Setup with 2D Camera and multiple lights.



Further hardware setups with different robots and area scanners, that can be managed by our framework.

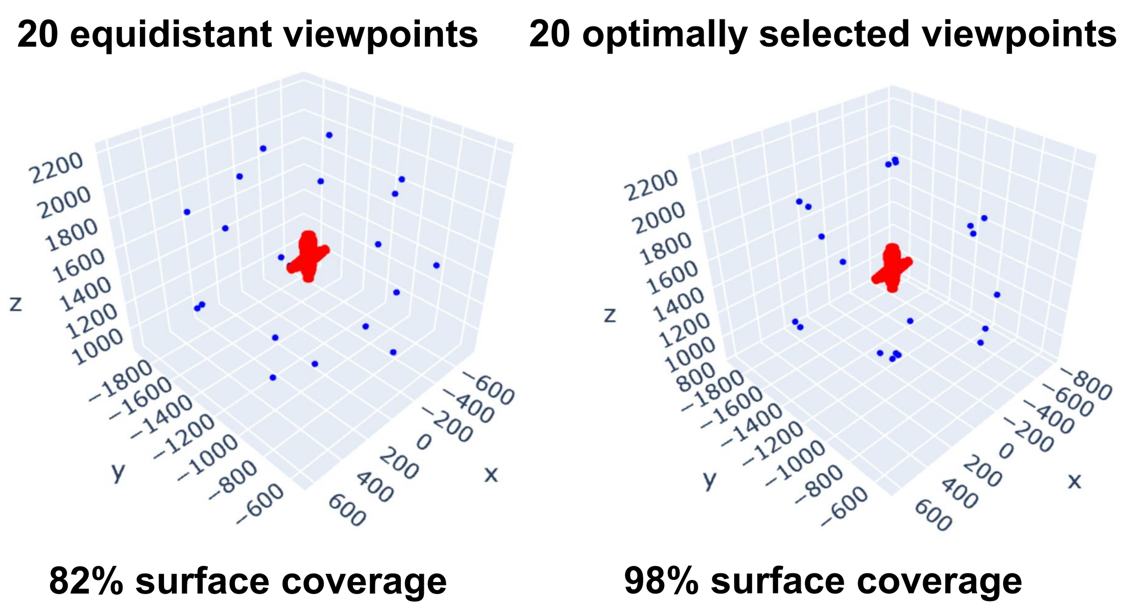
Approach – Software

We developed a framework that utilises the CAD to automate every single step of the quality inspection.



Viewpoint Optimisation

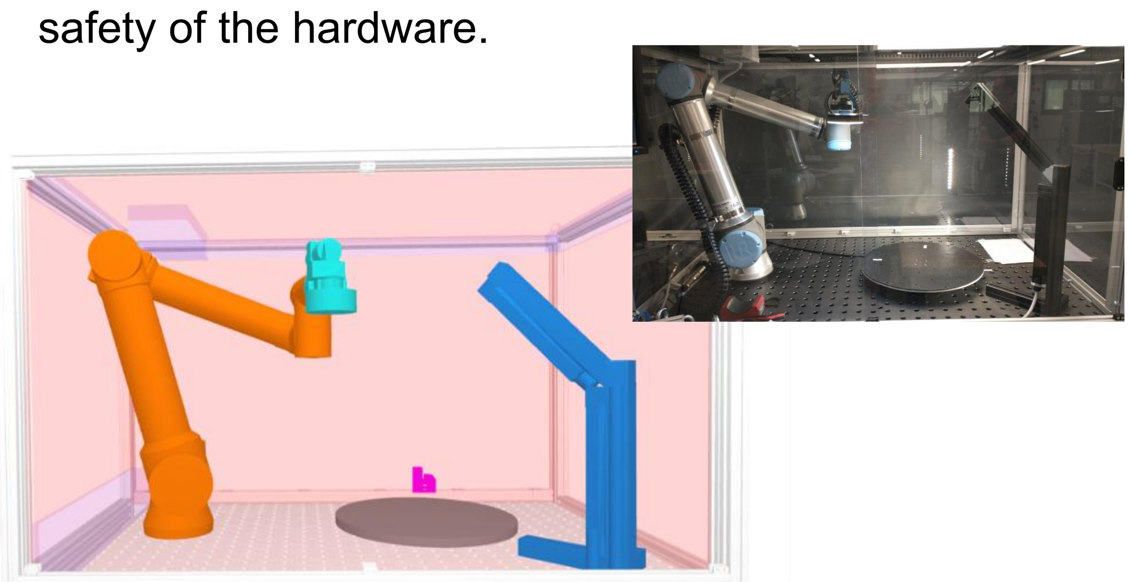
An algorithm uses the CAD model to automatically determine optimal sensor positions, ensuring complete surface coverage while minimizing the number of necessary views.



• For 2D inspection, each surface is scanned from different directions to maximise the visibility of defects.
• For 3D inspection, viewpoints are chosen to provide sufficient geometric variation in overlapping regions. This ensures robust markerless data fusion. [1]

Robot Path Planning

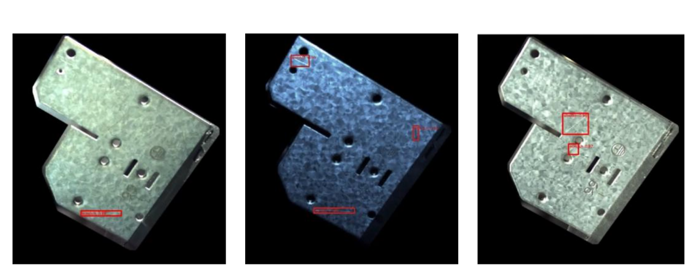
The robot moves the sensor to the selected viewpoints for data acquisition.
• The path is optimised to minimise travel distance.
• CAD-based simulation for collision detection ensures safety of the hardware.



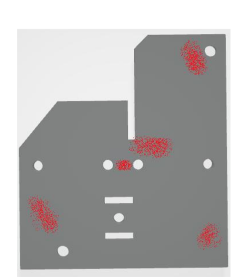
Digital Twin simulation of the environment and object to be scanned to plan optimal path without collisions.

Data Fusion for 2D Inspection

The recorded images are analyzed and combined on the 3D geometry of the CAD. Multiple deep learning architectures were evaluated for this fusion. [2]



Scratch detection on each image (same view, different light (angles).



Merged detection, visualised on the CAD.

Data Fusion for 3D Inspection

Captured point clouds are registered using a markerless alignment strategy based on geometrical fit. Evaluation can be done through visualizing the geometrical deviations w.r.t. the CAD, or by performing a detailed GD&T analysis.

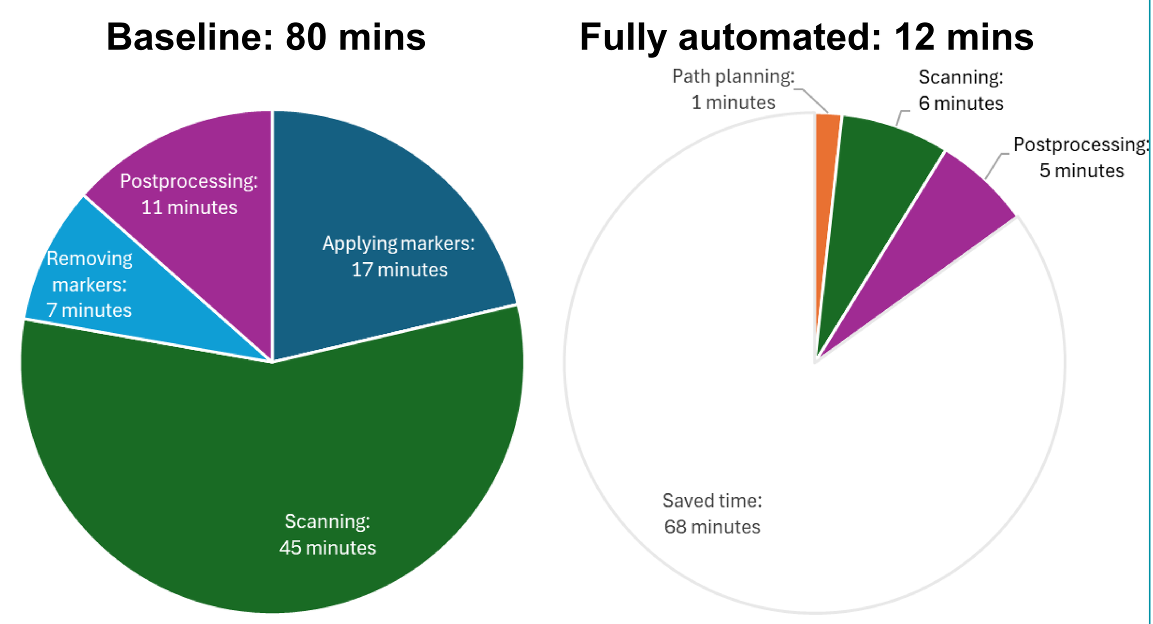
Results

We validated the inspection system on various industrial parts and sensors, including RGB cameras, fringe projection scanners (GOM Atos Core 200, Zivid2), and a laser snapshot sensor (Keyence LJ-S080).

Case Study

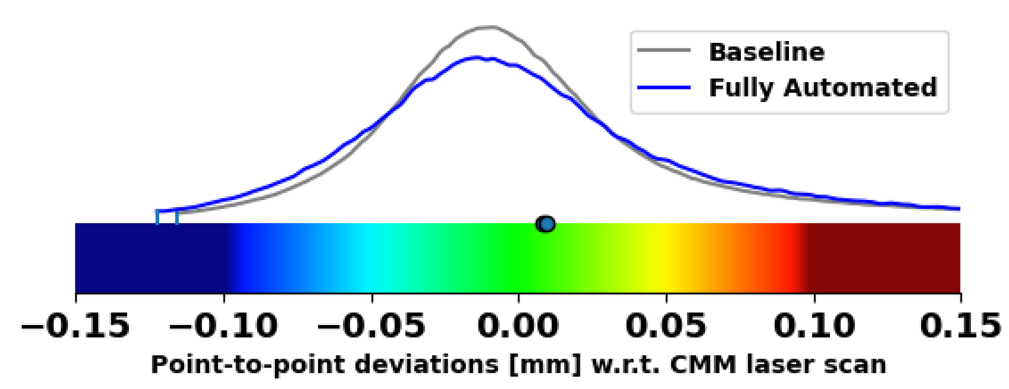
In a comparative study, automating the GOM Atos Core workflow significantly reduced scan time with minimal accuracy loss, compared to the manual marker-based process.

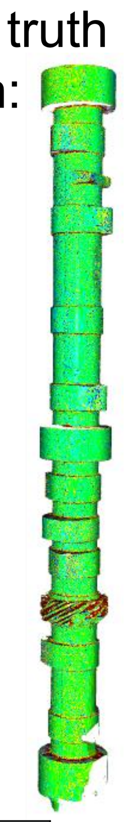
Evaluation of time



Evaluation of accuracy

Point-to-point deviations w.r.t. a ground truth scan with high point accuracy and resolution:





Evaluation of accuracy

Performance on cylindrical measurements:

Unit [mm]	Diameter 1	Diameter 2	Diameter 3
Tactile measurement	43,314	43,30	43,28
Baseline	43,316	43,29	43,29
Fully Automated	43,306	43,29	43,29

Key Take-aways

- Fully automated CAD-driven inspection planning and execution
- Fast, robust, repeatable inspection plans
- Supports multiple scanners and RGB cameras
- Markerless geometric inspection (no adhesive markers)

References

[1] Salaets, Rob, Vangilbergen, M., Bey-Temsamani, A., & Dehaeck, S. (2025). "Markerless Geometric Inspection Planning based on Greedy Algorithm with Registration Stability Constraint", OL2A 2025
[2] Bhavanasi, G., Neven, D., Arteaga, M., Ditzel, S., Dehaeck, S., & Bey-Temsamani, A. (2025). Enhanced Vision-Based Quality Inspection: A Multiview Artificial Intelligence Framework for Defect Detection. *Sensors*, *25*(6), 1703.

Contact:
sina.ditzel@FlandersMake.be

With the support of:

Aachen, Germany,
16 – 18 September 2025