

# Photogrammetry and Gaussian Splatting for traceable quality inspection: from 3D reconstruction to navigable scene representation

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## *Abstract*

Quality inspection of industrial assets and manufactured goods requires reliable evidence of geometry and surface condition at specific moments in time. In large-volume contexts such as aviation, maritime transport, wind energy and automotive manufacturing, decisions on safety, availability and maintenance require this evidence to be traceable, repeatable in practice and obtained without exposing operators to unnecessary risk. Nowadays, visual methods are widespread since they are adaptable and easily affordable, with photogrammetry gaining interest and attention; however, some limitations persist in operational use. Specifically, three-dimensional (3D) reconstructions (e.g., dense point clouds) can be locally incomplete when image coverage is insufficient, which leaves critical regions under-described. Information is also bound to the instant of acquisition, therefore, once the physical state evolves or access to the object of interest is lost, that initial condition cannot be revisited. These constraints hinder the ability to confirm whether an anomaly existed earlier but remained undetected or that of tracking the evolution of defects over time.

This thesis explores the concept of "*3D scene*" for the quality inspection of objects with the creation of a navigable, temporally coherent visual record, rather than a *static-in-time* capture. A 3D scene is defined as a high-fidelity digital realisation of an object or environment at a specific moment, coupling geometric description with appearance (i.e., colour, texture, opacity). Scenes can be generated from images collected during inspection, but their benefits reside in the capability of being explored from viewpoints that were not physically acquired. From the scene it is possible to produce synthetic images, i.e., renders, that emulate photographs while preserving the temporal state of the original acquisitions. Integrating these renders into a photogrammetric workflow may increase local coverage without the need for new physical imaging. The scene can capture and preserve each specific inspection moment, enabling retrospective exploration at any future time: this capability outlines the novel paradigm of "*back-in-time repeatability*".

The first part of this thesis conducts a comparative evaluation of photogrammetry across different dimensional scale domains, assessing performance and creating a statistical quantitative analysis that accounts for the most relevant sources of uncertainty.

In the second part, the concept of the 3D scene generated through the recent technique of Gaussian Splatting (GS) is introduced within the manufacturing context. GS is preliminarily coupled with photogrammetry to increase the local density of the 3D reconstruction. A multicriteria operational and quantitative evaluation is then conducted to compare photogrammetry and GS. Finally, GS is explored as a standalone technology for defect detection and tracking over time.

Specifically, this thesis is organised as follows:

- Chapter 1 presents the motivation for the research within an industrial context. Furthermore, it highlights the limitations of photogrammetry and introduces the 3D scene as a potential solution to those limitations with focus on GS.
- Chapter 2 presents the fundamentals of photogrammetry and outlines the metrological background used to compare photogrammetric performance across different scales of interest. Furthermore, the chapter describes the operational criteria used to compare photogrammetry across *small*- and *meso-scale* domains, with the aim of systematically investigate the photogrammetric performance when the scale of objects under consideration changes.
- Chapter 3 describes the main temporal limitations of photogrammetry and introduces the concept of 3D scene in manufacturing. A significant portion of the chapter is given to the fundamentals of GS and to the innovative paradigm of *back-in-time* repeatability. Furthermore, the chapter proposes a synergistic integration between photogrammetry and Gaussian Splatting, with some experimental results in both manufacturing and medical sectors.
- Chapter 4 compares photogrammetry and GS from multiple perspectives. Preliminarily, the comparison assesses the metrological capabilities of the technologies across a multiscale scenario. The second part of the chapter addresses the operational performance evaluated across a series of subjective and independent criteria.
- Chapter 5 discusses a semi-automatic inspection activity carried out with the use of GS as standalone technology, without being supported by photogrammetry. The chapter introduces the proposed methodology and some indicators for performing defect detection on the object under consideration, i.e., an automotive brake disc.
- Chapter 6 gives a summary of the present work and some concluding remarks to highlight the major outcomes of this thesis. Some research ideas are proposed as topics for future investigations.