The Use of Close-range Photogrammetry and 3D Scanning for Diagnostic Purposes in Mechanical Engineering

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Abstract

This article uses a case study to demonstrate the advantages and disadvantages of different photogrammetric technologies in practice. Close-range photogrammetry and 3D scanning technologies are increasingly used in engineering diagnostics due to their ability to deliver precise, non-contact measurements of complex components. This study evaluates and compares several such technologies—Linearis (code-target photogrammetry), image-based modeling and rendering (IBMR) using Agisoft Metashape, and the combined MAXSHOT 3D and HandySCAN 3D BLACK system. All these systems were applied to the spatial analysis of a large, 100-ton metal block forming the core of an engineering press. The objective was to assess the accuracy, efficiency, and practical usability of each method in determining spatial relationships, flatness, and parallelism of key structural elements. Results show that while IBMR offers simplicity and low cost, it requires defined scaling. Linearis provides good accuracy but is limited in image count and precision in used Lite version. The MAXSHOT 3D and HandySCAN 3D BLACK system proved most accurate, offering high-density point clouds suitable for CAD integration, albeit with higher costs and operational complexity. The choice of technology ultimately depends on required precision, object complexity, and resource availability. This case study underscores the importance of selecting appropriate 3D measurement tools based on specific diagnostic needs in industrial environments.

1. Introduction

Close-range photogrammetry and 3D scanning are finding increasingly wider application in the diagnostics of engineering equipment thanks to their ability to provide detailed and accurate spatial information about the geometry and condition of components (Luhmann et al., 2014). These technologies enable non-contact measurement and visualization of surface defects, deformations, or wear of components, which significantly streamlines quality control, predictive maintenance, and reverse engineering processes (Remondino & El-Hakim, 2006). By avoiding the need to disassemble equipment, they also help reduce downtime and associated labor costs.

The most used methods include close-range photogrammetry, laser 3D scanning, structured light scanning, industrial computed tomography (CT scanning), and mobile 3D scanning systems (Salvi et al., 2004; Ma et al., 2019, Gautier et al, 2020). Each of these technologies offers unique advantages and limitations, and the choice of method typically depends on the specific requirements of the project, such as the size and complexity of the object, desired accuracy, budget, and working conditions.

In modern practice, these technologies are often integrated with powerful analytical software tools that support a wide range of applications—including comparison with original design models (CAD), detection of geometric deviations, assessment of dimensional wear over time, and integration into predictive maintenance workflows (Kersten & Lindstaedt, 2012; Sansoni et al., 2009). The resulting digital models and datasets offer a high level of precision, which can be used not only for diagnostics but also for documentation, replication, or further design modification.

Compact handheld scanners have significantly improved the flexibility of data acquisition. Their portability allows measurements to be carried out directly in operational environments, even under less-than-ideal conditions. These devices are well-suited for rapid geometry verification, CAD model comparison, or quick assessment of a component's current state, especially in field settings where time and space are limited (Fassi et al., 2013, Semančík et al, 2023).

Photogrammetric systems also exist in various configurations, ranging from simple image-based modeling to more complex coded-target systems designed for high-accuracy metrology tasks. A major advantage of photogrammetry is its scalability and the ability to capture fine detail without contact. However, challenges remain in establishing precise scale and alignment. These systems often require well-defined geodetic control points or calibrated measurement standards to ensure dimensional accuracy, especially in large-scale or high-precision industrial applications (Fraser, 2013, Zahradník et al, 2023, Zahradník, Roučka, 2024).

Our research focused on the practical application of these technologies to define the shape and spatial configuration of a large and extremely heavy metal block, forming the base of an engineering press. This component, due to its size and weight, could not be moved or disassembled, making non-contact 3D measurement the only feasible solution. The primary goal was to accurately determine the spatial relationships between individual structural features—such as machined surfaces, guide runners, flange interfaces, and internal shaft mounting components—across two separate stands of the press. This information was crucial for evaluating part alignment and fitment in the overall assembly, with implications for both performance and longevity of the machinery.

2. Methods and used technologies

Various technologies were used, which were then compared in terms of accuracy, speed, price, and processing time.

1) Linearis. This is a photogrammetric system that uses code targets, a calibrated Nikon D3200 digital SLR camera, and dimensional standards. The targets must be affixed to the object.

2) IBMR technology. This method uses only digital photographs taken from different angles to create a 3D model of the object and software. In this case, Agisoft Metashape was used, which generated a dense point cloud and mesh from the photographs. The advantages are simplicity, relatively high accuracy, and the ability to document even complex shapes without physical contact. Photos taken for the Linearis system were used.

3) MAXSHOT 3D and HandySCAN 3D BLACK. Using the MaxSHOT 3D optical 3D scanner, a network of registration points was first targeted, which was then used for the precise registration of individual scans taken with the HandySCAN 3D BLACK. The results of the measurements are CAD objects that will be used for the subsequent evaluation of mutual spatial relationships. The quality benchmark for the interpolation of individual elements is the standard deviation characterizing the distribution of residual distances between the interpolated element and the scan. Errors ranged from 19 to 59 micrometres. Furthermore, point clouds were compared using CloudCompare software, with the third technology, Maxshot 3D and HandyScan, being taken as the most accurate (reference) model. The research in this case study demonstrated the different usability of the systems used.
The photogrammetric IBMR method is the simplest but requires a scale to be defined. The Linearis photogrammetric system is very accurate, but the object must be covered with targets, and unlike the specifications in the manual, our version can only take 500 images and has an accuracy of tenths of a millimetre. The higher version has an unlimited number of images and an accuracy of up to hundredths of a millimetre.
The disadvantage is that point measurement is only possible at marked points, which is not always suitable. The combination of Maxshot 3D and Handyscan is laborious, uses expensive equipment, but is very accurate and generates a dense point cloud. The use of technology is therefore highly dependent on the required accuracy, output, and type of object being diagnosed.

3. Case projects

To find out today's possibilities of precise modeling and analyzing of a mechanical industrial part, the engineering press was selected. The basic part of this instrument is a metal block. It weighs more than 100 tons with diameters of 2x4x3 meters (Figure 1). In the block, there are several holes for large bearings and other technical elements. The aim of the measurement was to determine the accuracy of the part in terms of flatness and parallelism of the holes created for the bearings. The work was carried out in Prague, at a specialized metallurgical and engineering company in the Czech Republic.

Figure 1. Example of an engineering press

4. Data capturing and processing

Probably the simplest method of creating 3D models is based on close-range photogrammetry, as it is simple, inexpensive, and does not require expensive scanners. It is based on calculating the internal and external orientation of cameras using Structure from Motion (SfM) technology, which generates a sparse point cloud. Subsequently, depth maps are usually generated using Multi-View Stereo (MVS) technology, from which a dense point cloud and then a polygonal mesh can be reconstructed. In newer versions, the mesh can be generated directly from depth maps, which can be more efficient in terms of computing power. This is true if the result is to be a model. The resulting model is usually supplemented with texture derived from the original images.
This process is typical for desktop applications, especially for the best-known Agisoft Metashape (Figure 2).
However, there are also specialized technical systems that require additional hardware and are generally specialized for very accurate technical measurements.

The most accurate comprehensive system, MAXSHOT 3D and HandySCAN 3D BLACK, was taken as a reference. Measurements from Linearis and Agisoft Metashape were compared with it.

Image Capture
taking overlapping photos
⇩
Structure from Motion (SfM)
calculating camera orientation and creating a sparse point cloud
⇩
Multi-View Stereo (MVS)
generate depth maps and dense point clouds.
⇩
Mesh Generation
conversion of points to a polygonal mesh.
⇩
Texture Mapping
applying textures from photos to a mesh

Figure 2. Flow chart of a typical automated photogrammetrical process for creating of a 3D model

4.1 Linearis

Linearis is an older system for precise point measurement that uses code labels for photo orientation and small targets for detailed points. The problem with photogrammetry is that the results are usually in model coordinates, without scale or with an approximate scale. Traditionally, it is used for transformation into a geodetic system and for defining the scale of ground control points that are geodetically measured. For mechanical products, the use of a geodetic reference system is not necessary, but it is very important to define the dimensions precisely (Figure 3-6).

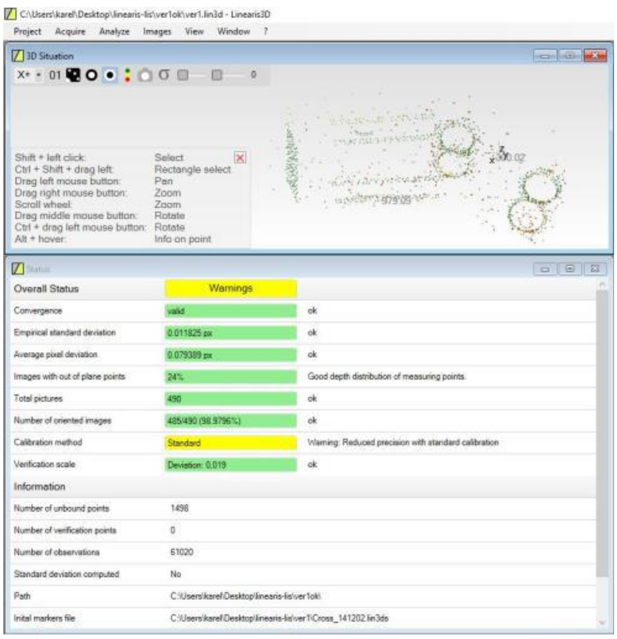

Figure 3. Computing of the shape, Linearis, photogrammetry with coded targets

For this purpose, the Linearis system uses a freely attachable cross scale and a linear scale. Both have defined dimensions, are provided with code marks, and give the measurement dimensions.
The measurement procedure is not complicated: self-adhesive code discs are affixed to the object so that at least four are visible in each image of the object, The entire object is marked with small round self-adhesive targets to define detailed points, and the object is photographed with a calibrated SLR camera with a fixed focal length without the possibility of refocusing or autofocus. The images are uploaded to the software, where the code discs and marked points are detected, block adjustment is performed, and the results are displayed in a table. The result is a set of detailed points on the object. In this case, an older lite version was used, which unfortunately has a limit of 500 images, even though the manual states that there is no limit. The Lite version also has a limitation in terms of accuracy, with results accurate to tenths of a millimeter. The higher version has an unlimited number of images and accuracy to hundredths of a millimeter, but the procedure is the same.

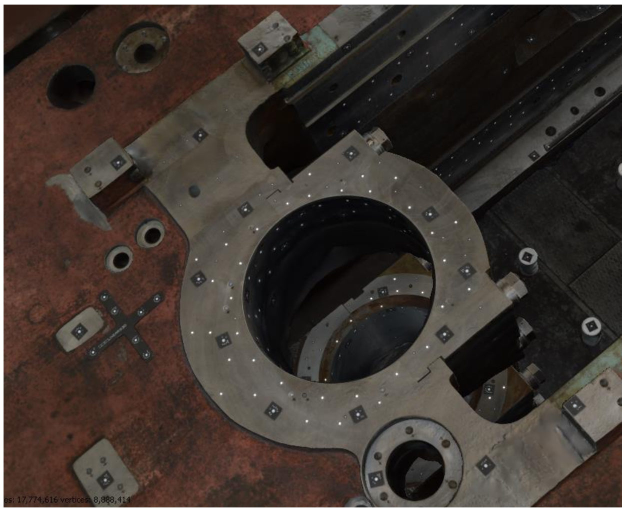

Figure 4. Photogrammetrical processing, Linearis system

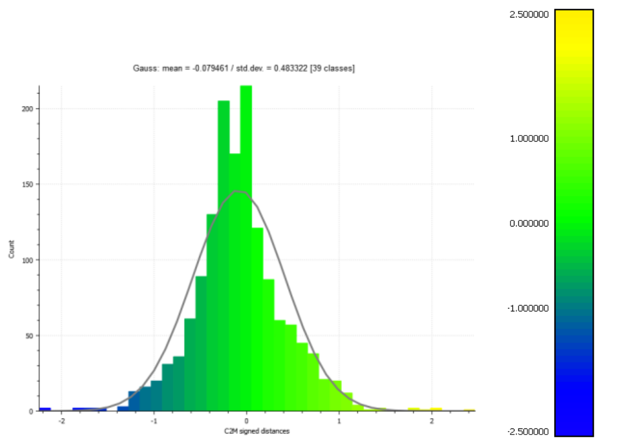

Figure 5. Histogram, Agisoft Metashape in comparison with 3D points from Linearis (horizontal scale and the histogram scale are both in milimetres)

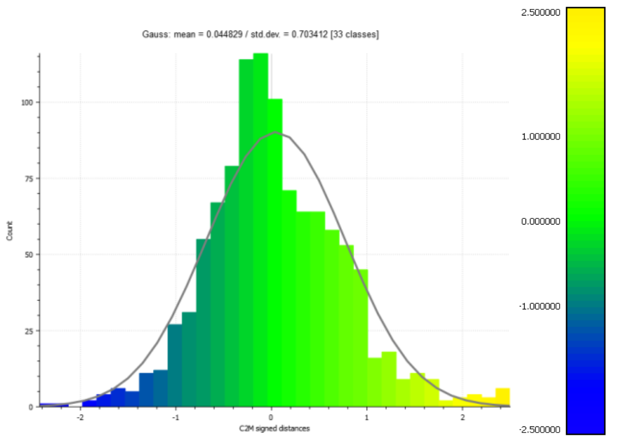

Figure 6. Histogram, scanner MAXSHOT 3D and HandySCAN 3D BLACK in comparison with 3D points from Linearis (horizontal scale is in milimetres)

Figure 7. Agisoft Metashape, in comparison with 3D points from Linearis

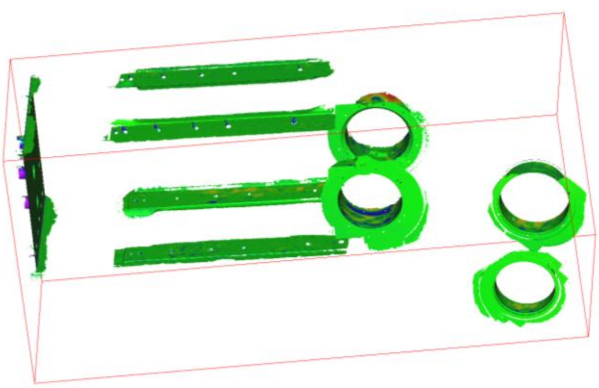

Figure 8. Scanner MAXSHOT 3D and HandySCAN 3D BLACK, output of the measurement

4.2 Agisoft Metashape

Processing in Agisoft Metashape is one of the most widely used procedures in modern close-range photogrammetry. The procedure is shown in Figure 2. It is based on a set of overlapping images taken from different angles so that the entire object is sufficiently covered by the images. The number of images depends on the size of the object and its spatial shape but generally involves hundreds of images. The result is a point cloud or mesh. The procedure is intuitive and automatic. However, it is necessary to adhere to the basics of photogrammetry, which ordinary users often fail to do (Figure 7, 9-10).

Figure 9. Output from Agisoft Metashape

Figure 10. Detail of the 3D model created in Agisoft Metashape (pointcloud)

4.3 MAXSHOT 3D and HandySCAN 3D BLACK

Using the MaxSHOT 3D optical 3D scanner, a network of registration points was first targeted, which was then used for the precise registration of individual scans taken with the HandySCAN 3D BLACK. In the first step of post-processing, the network of 113 registration points was aligned.

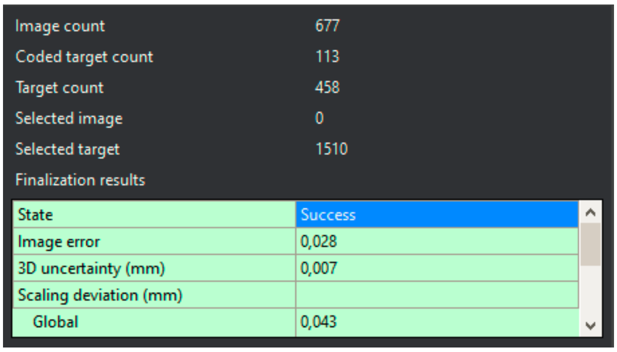

Figure 11. Results of photogrammetric measurement alignment

A final scan was then created from the HandySCAN 3D BLACK data. The surfaces of individual elements (cylinders and planes) were selected from the final scan using an automatic method (region growing), which were then intersected with planes and cylinders. CAD objects were created from these intersections. The cylinders were converted directly into CAD objects, and the surfaces were extracted in the normal direction to the solids (cubes), Figure 8, 11-14.

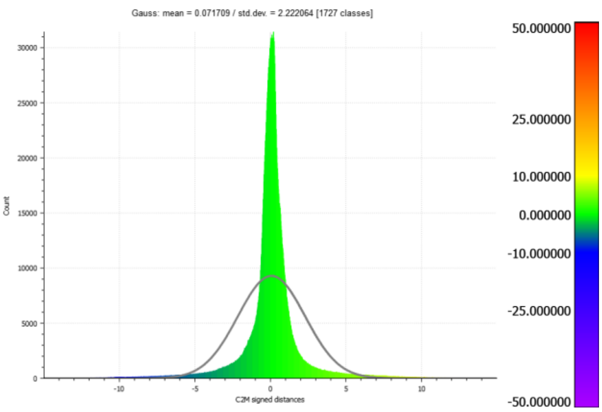

Figure 12. 4.3 MAXSHOT 3D and HandySCAN 3D BLACK comparison with results from Agisoft Metashape (horizontal scale and the histogram scale are both in milimetres)

The quality of the interpolation of individual elements is measured by the standard deviation characterizing the distribution of residual distances between the interpolated element and the scan (Figure 12-14).

Part, small stand	std surface interleaving [mm]
lower horizontal surface	0.0206
left front surface	0.0212
left rear surface	0.0364
right front surface	0.0287
right rear surface	0.0326
lower front cylinder	0.0191
lower rear roller	0.0513
upper front cylinder	0.0216
upper rear cylinder	0.0348
lower front mounting flange	0.0203
lower rear flange 1	0.0255
upper front flange	0.0378
upper rear flange 1	0.0494

Table 1. Standard deviations of surface interleaving (model and measured part)

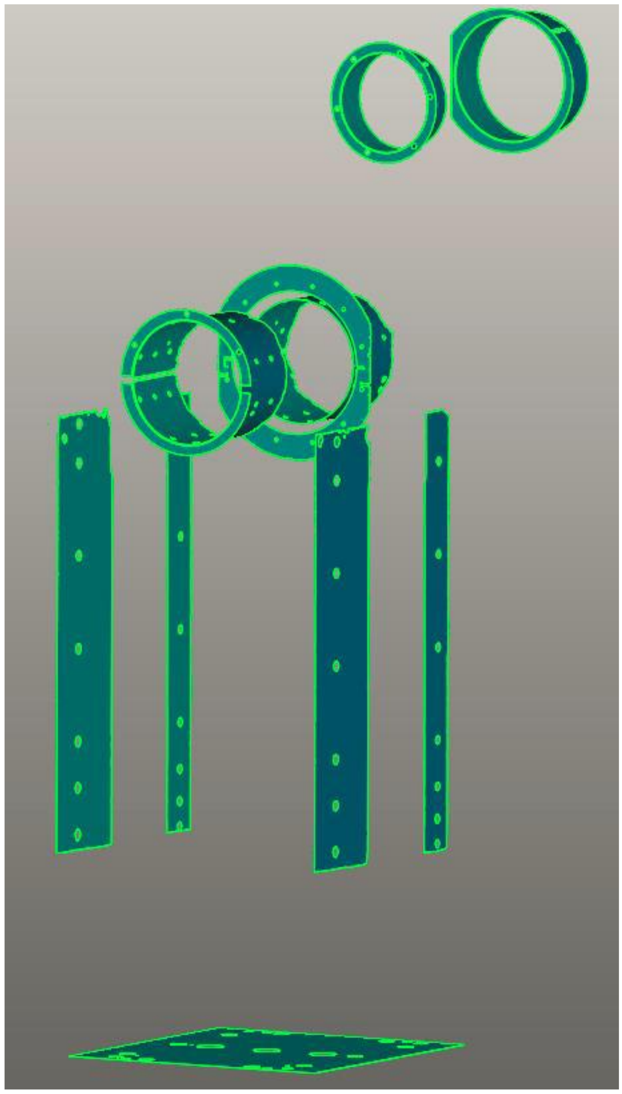

Figure 13. Design of ideal primitives in CAD

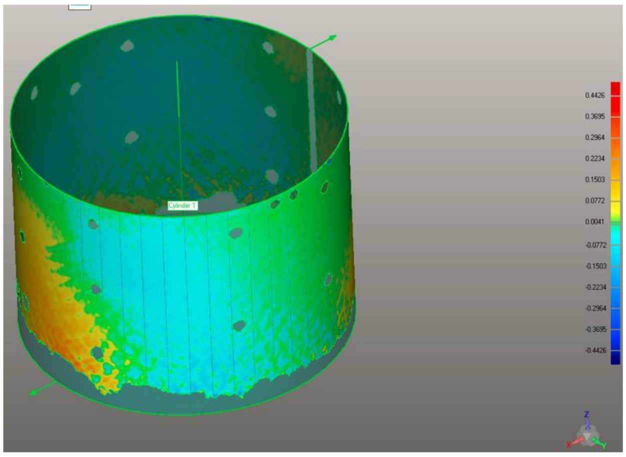

Figure 14. Deviations from the ideal shape, maximum tenths of a millimetre

5. Conclusion

The Linearis system used here in its lite version is limited to 500 images and has a limited accuracy of tenths of a millimeter, which is determined by the detection of the centers of the targets. The disadvantage is the labour-intensive placement of code targets and targets for detailed points; logically, the number of defined points will be limited, in this case approximately 1,500 points.

The advantage is fast data processing and the simplicity of the measurement itself, which consists of photographing the object. However, it is necessary to have at least four code targets on each image. The Agisoft Metashape system uses general images with sufficient overlap, has no restrictions on the number of images or accuracy, and does not require artificial signaling if the surface of the object has a good texture. The targets from the Linearis measurement and the fact that the machined metal casting was slightly rusted were advantageous here.

A total of 850 images already captured from Linearis were used for the calculation. According to the diagram in Figure 4, Agisogt Metashape first calculates the orientation of the images, i.e., the external and internal orientation elements, then calculates the mesh, and the point cloud can be calculated subsequently, including the texture. The calculation time on a standard computer (16GB RAM, NVIDIA QUADRO P1000) takes quite a long time, on the order of hours with the high setting used. However, the result is fundamentally different from the Linearis system.

The created mesh had 50 million triangles, and the point cloud had 150 million points, compared to approximately 1,500 points from the Linearis system. Thanks to the calibrated mirror, the results are comparable to the Linearis system in terms of accuracy.

The latest MAXSHOT 3D and HandySCAN 3D BLACK system uses two steps, which consist of defining the object and collecting detailed points; these are two technologies used in sequence.

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