Building Simulation Capabilities

Investigation into the use of 3D scanning and reverse engineering for machine simulation

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1 Introduction

When using CAM and G-code simulation programs such as SolidCAM and Vericut, an accurate model of the machine needs to be set up in the software to have an accurate representation of the machining process. Often with older machines or custom tools and fixtures these models don't exist.

This project investigates the workflow and challenges of recreating a digital model of CNC machines and tools using the EinScan Pro 2X 3D scanner and Geomagic Design X to reverse engineer the scans. These models will then be setup for simulation of the CNC machines.

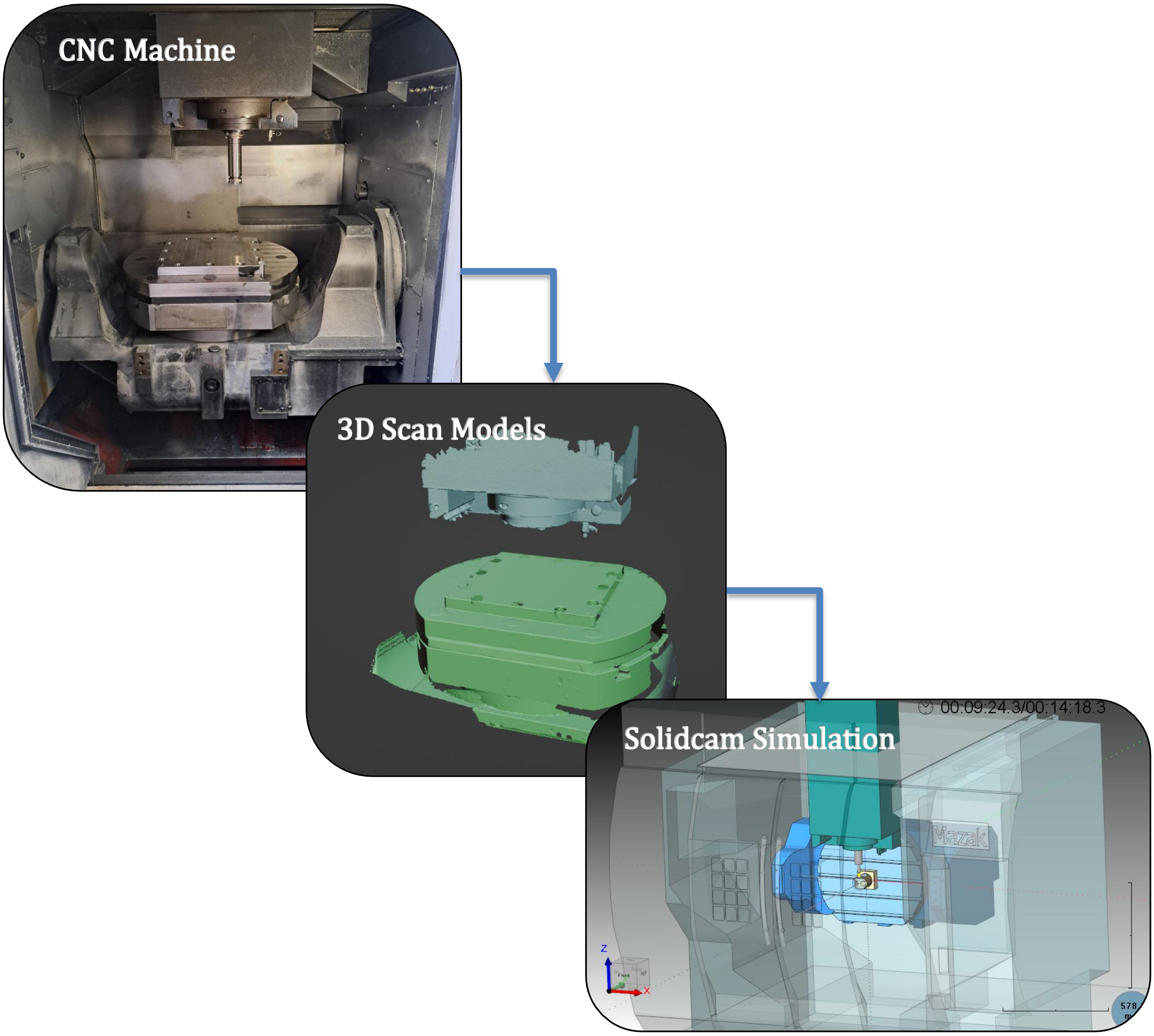


Figure 1 - Reverse Engineering Process

2 Investigation

This section will cover the methodology of reverse engineering through the use of a 3D scanner for data collection and the factors that effect the quality of the end result.

2.1 3D Scanning and Reverse Engineering Process

A brief overview of the process of reverse engineering with a 3D scanner is shown below to give more clarity to the following technical discussion.

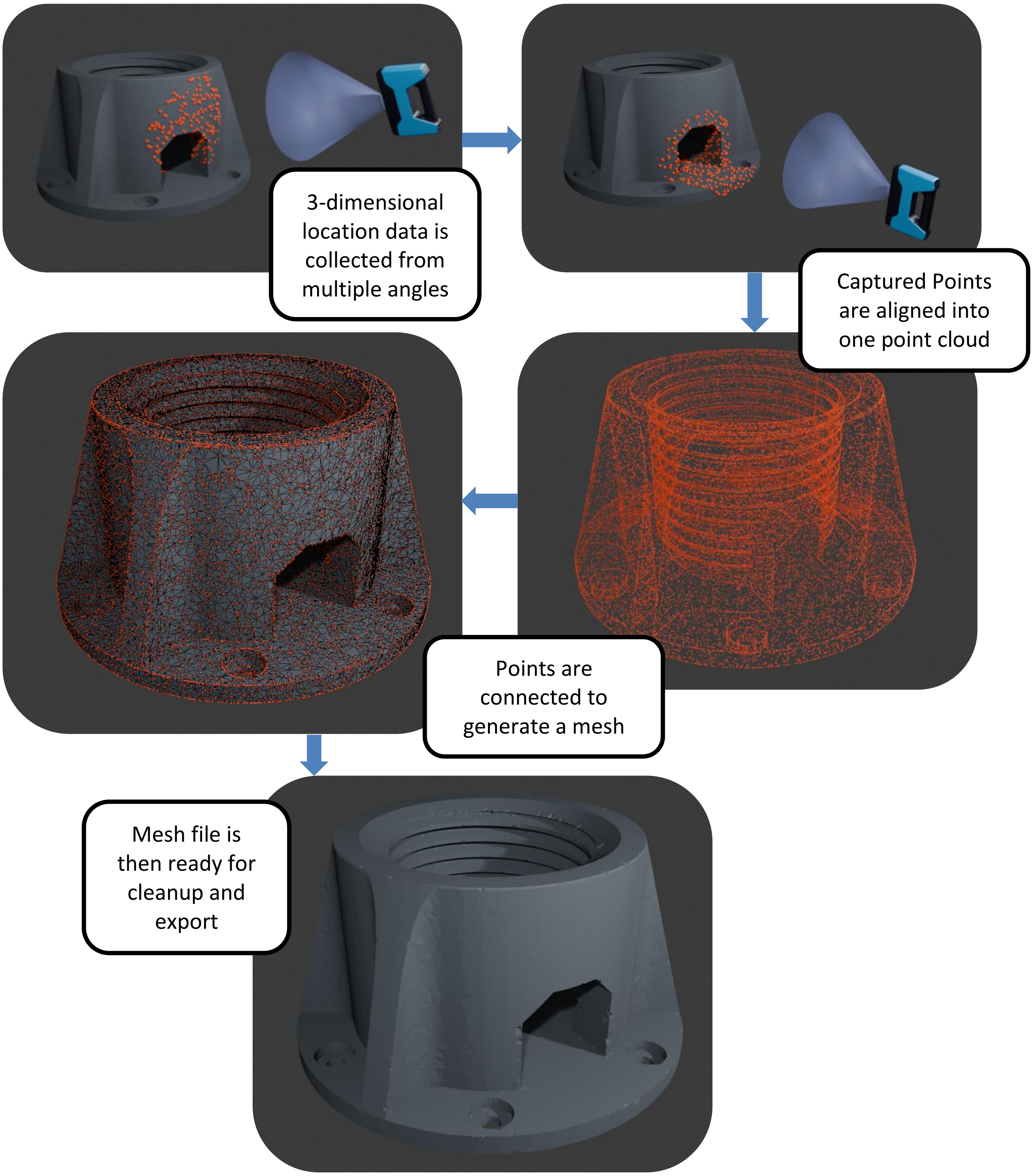


Figure 2 - 3D scanning process

3D models that are generated through this process are a mesh representation of an object. A mesh file represents a 3D object using a collection of vertices, edges, and polygonal faces (typically triangles) to approximate its surface, making it ideal for real-time rendering, 3D printing, and simulations due to its simplicity and computational efficiency. In contrast, a NURBS (Non-Uniform Rational B-Splines) file defines 3D geometry using smooth, mathematically precise curves and surfaces controlled by weighted control points, allowing for accurate, high-quality representations suited for engineering, CAD, and industrial design applications. While mesh files are more commonly used in graphics and gaming, NURBS files are preferred in industries requiring precise, smooth, and highly controllable geometry.

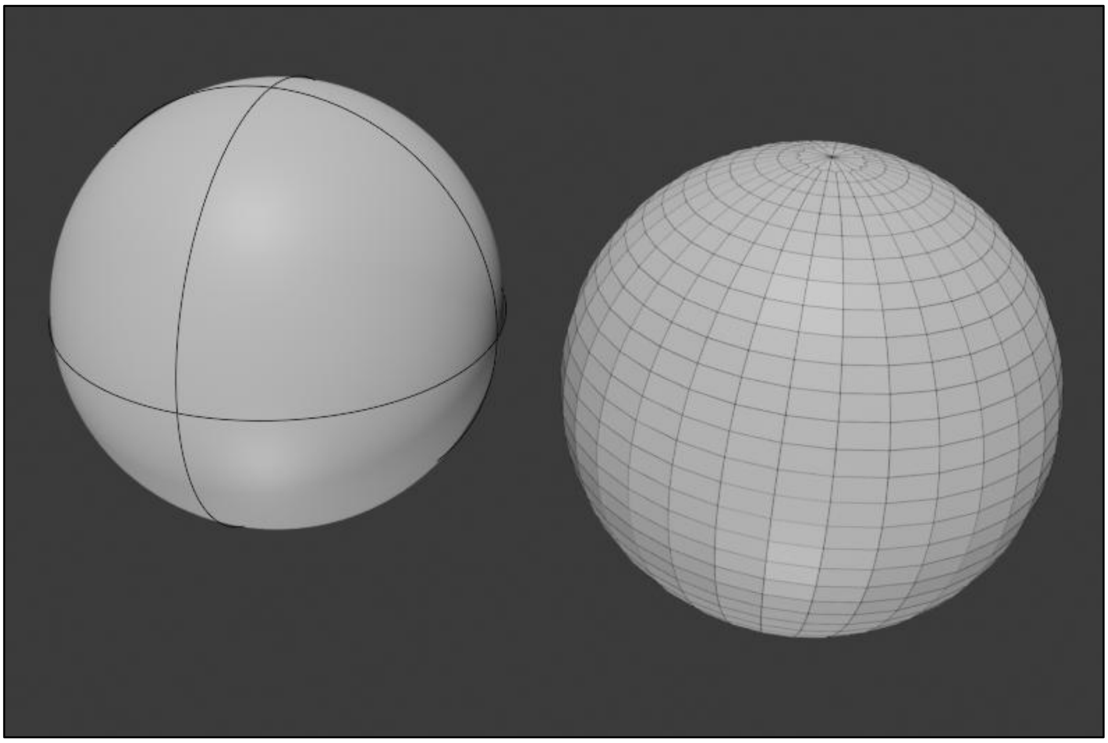


Figure 6 - Sphere as a NURBS and Mesh Representation

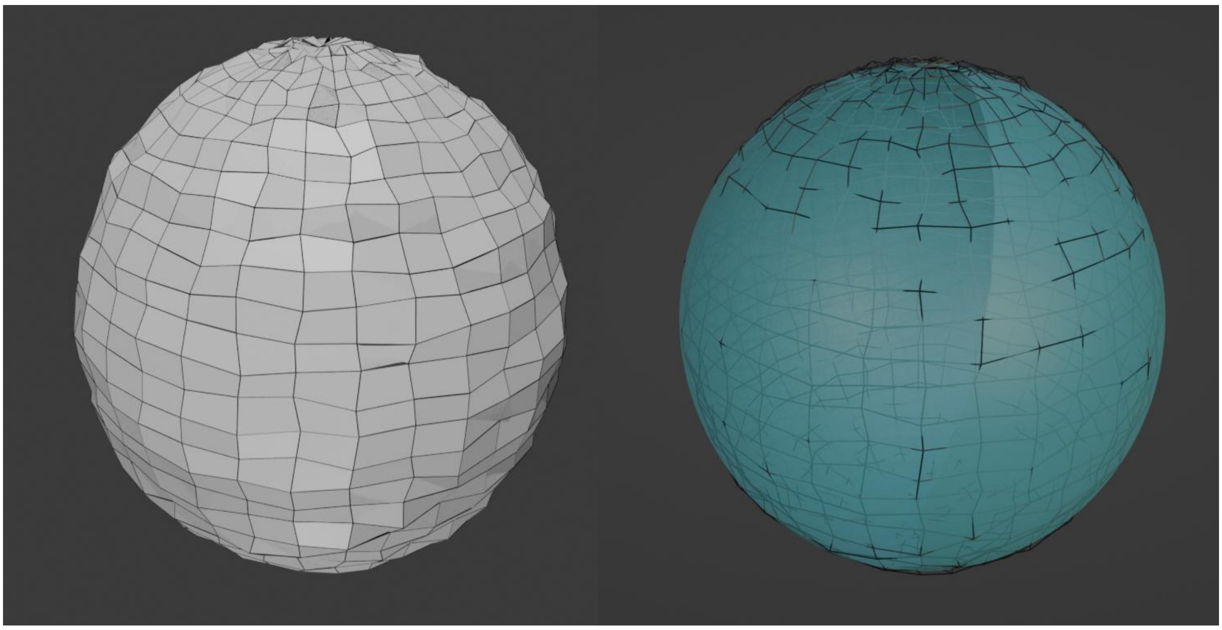


Figure 4 - Surface fitting of a sphere to a mesh

3D scans are not perfect representations of objects due to noise, gaps, and inaccuracies caused by scanning limitations such as occlusions, reflections, or sensor errors. These raw scans often require reverse engineering to convert them into accurate, editable NURBS models. This process involves statistical techniques like surface fitting, averaging, and regression analysis to smooth out noise, fill in missing data, and create a mathematically precise representation of the object's shape. By using statistical methods to optimize control points and curve continuity, a NURBS model can be generated that closely approximates the intended design, making it suitable for CAD, manufacturing, and engineering applications.

2.2 3D Scanning Equipment

Figure 8 - EinScan Pro 2X (Einscan, 2018)

DAMRC owns the EinScan Pro 2X 3D scanner which is designed for handheld scanning of small to medium sized parts (Einscan, 2018). For small parts the scanner is capable of a resolution of 0.2mm at an accuracy of 0.045mm while for larger parts, and a rapid scan can be set up to a resolution of 3 mm at an accuracy of 0.1mm. For the use case of models for CNC simulation, the model needs only to have an accuracy larger than that of the safety distance. The safety distance in simulation is the threshold for how close two parts of the CNC model can be before giving a collision alarm. Generally, between machine components the distance is set to 1mm or higher, thus a rapid scan accuracy of 0.1mm is suitable for most simulations.

One of the most critical aspects of 3D scanning is the reliability of object tracking. For a successful 3D scan, the scanner needs to be able to keep track of its position in relation to the scanned object so that the features it scans are correctly placed in the digital model. The EinScan is capable of multiple methods of tracking and alignment, all with pros and cons.

Figure 10 - Turntable Scanning (Einscan, 2018)

Table 1 - Alignment Comparison Table (Einscan, 2021)

Alignment Method	Description	Best For	Limitations
Feature Alignment	Aligns data from multiple scans based on the object's geometric shape.	Objects with distinct, rich features.	Struggles with featureless or repetitive patterns.
Turntable Marker Alignment	Uses marker points on the turntable for alignment as it rotates.	Objects placed on a turntable with visible marker points.	Large objects may obscure marker points, affecting alignment.
Marker Alignment	Requires markers to be placed on the object's surface; alignment is based on these markers.	Objects lacking distinct features.	Time-consuming to place markers; not suitable for all surfaces.
Turntable Alignment	Uses the relative position between the turntable and the scan head, established during calibration.	Objects that do not obscure the turntable's coding points.	Requires recalibration if the relative position changes.
Texture Alignment	Uses the texture (colour and pattern) of the object's surface for alignment.	Objects with rich, distinct textures.	Ineffective for objects with uniform or low-contrast textures.

Data that is captured from different angles or scanning sections is aligned based on the alignment and tracking data. When two regions have overlapping data points, these points are marked as regions of higher accuracy since they have been referenced in relation to more than one set of data points. Below shows this concept with a blue and red data set overlapping to create a region of higher accuracy shown in green.

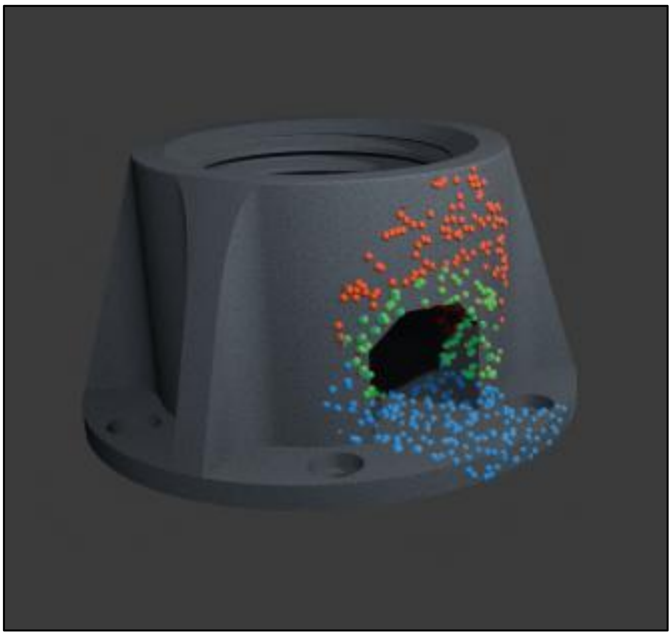


Figure 12 - Scan Data Alignment

Figure 13 - Scan Data Alignment

With objects that have large flat surfaces, such as CNC machines, markers or textures are needed to be able to track the scanning process. When using markers the tracking is highly accurate and consistent, but at least 3 markers need to always be in view of the scanner for accurate tracking. With the largest scanning area being 250x200mm, large objects require large quantities of markers. As an estimate, given a 50x50cm plate, the markers will need to be placed with an average spacing of 10cm to have all regions covered by the scanner with at least 3 markers visible. For such a panel, an estimate of 21 markers would be required.

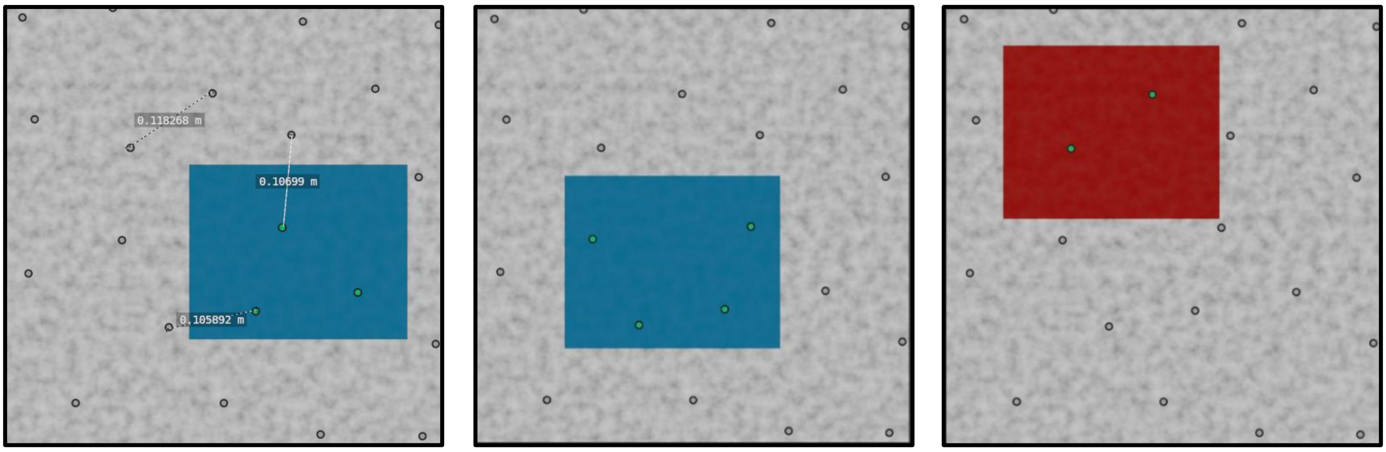


Figure 14 - Markers on Scan Area

Figure 15 - Markers on Scan Area

As a real-world example, when scanning a desktop hydraulic press, over 200 tracking dots we required to achieve a usable scan.

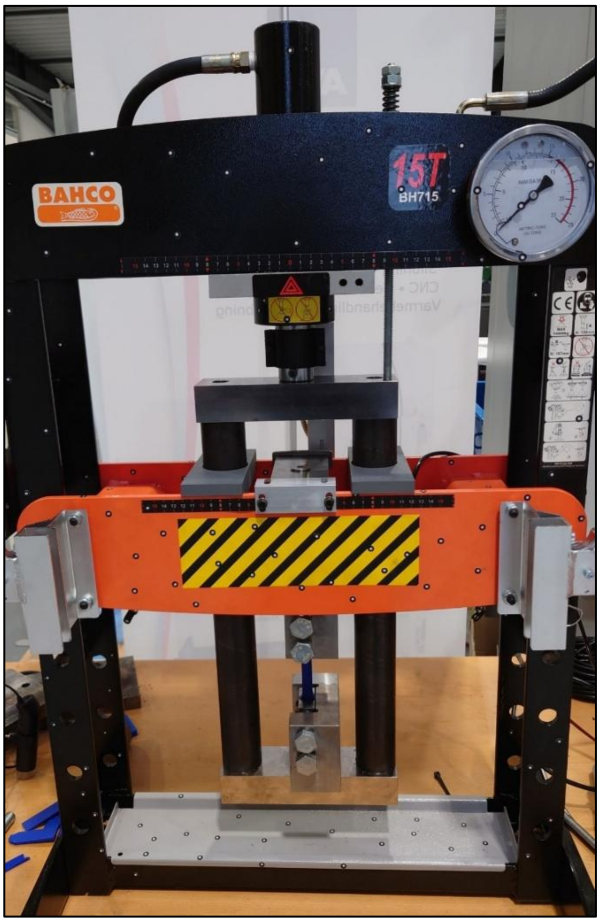


Figure 16 - Markers on Hydraulic Press

In comparison, when scanning with texture tracking, each distinct change in colour can be used as a tracking point. This greatly increases the ease and speed of scanning, especially on flat surfaces. If a surface

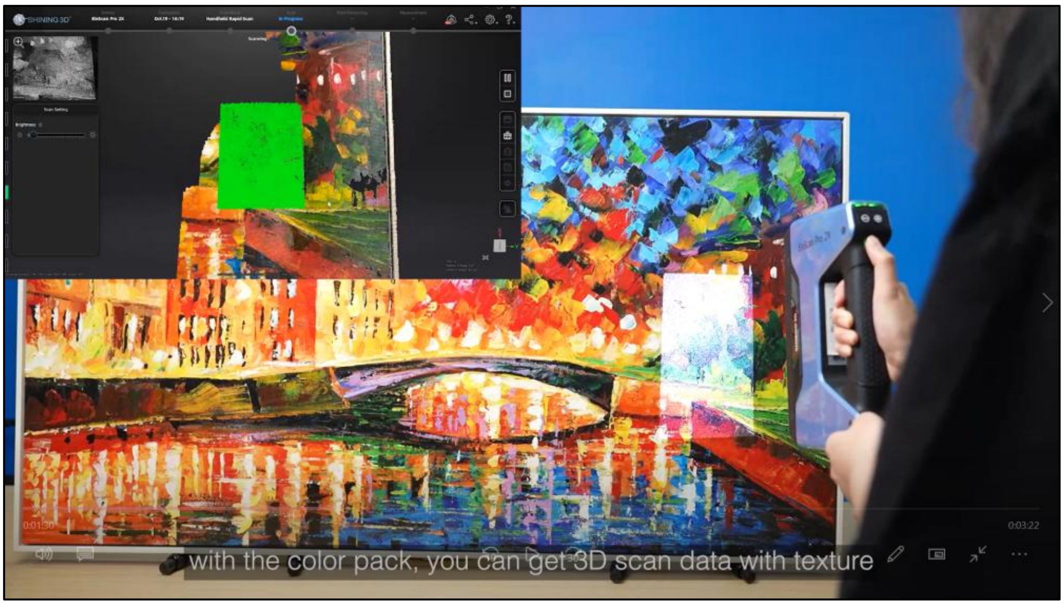


Figure 18 - Texture tracking on flat painting (Einscan, 2021)

is smooth with no distinct texture, temporary paint splatter can be used to quickly add thousands of tracking points.

3 Scanning and Reverse Engineering Test

This section will cover the process of 3D scanning the internals of a CNC machine for the use of reverse engineering and machine simulation. The test will be an example of how an existing machine with no available 3D model can be recreated and show the difficulties that arise in the process.

3.1 Mazak Variaxis 630M

DAMRC's 5 axis mill for which there is no readily available 3D model was chosen as an example of the process.

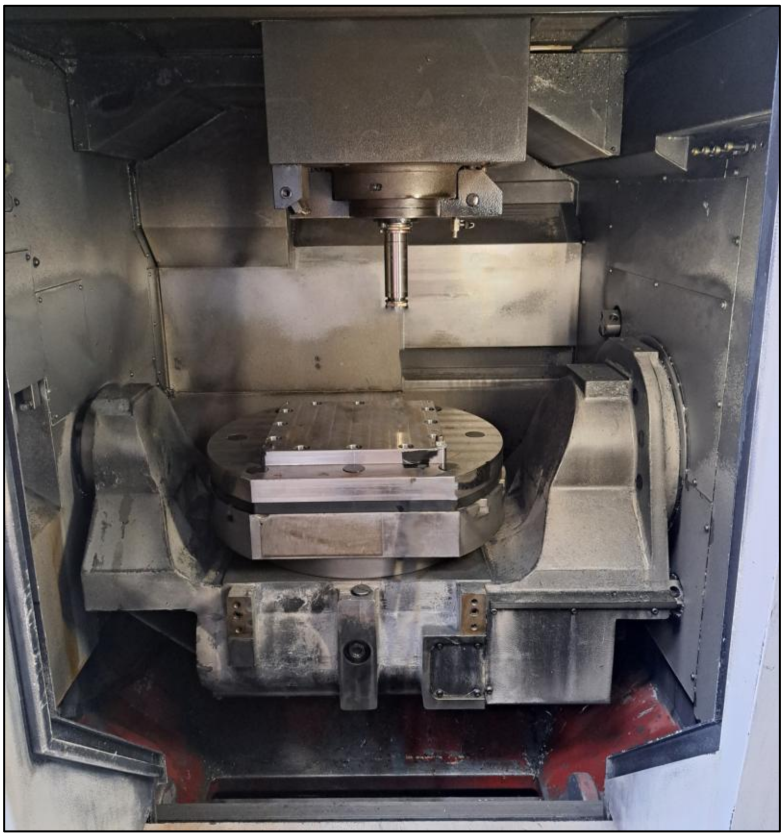


Figure 20 - Mazak 630M

Figure 21 - Mazak 630M

Scanning of the internals took approximately 5 hours. This length of time was mainly due to the requirement of placing markers for tracking, rescanning of misaligned regions, and loss of tracking on large regions that needed additional markers. When scanning metallic surfaces, temporary chalk spray was required to scan the surfaces correctly. The end result of the scanned regions is shown below.

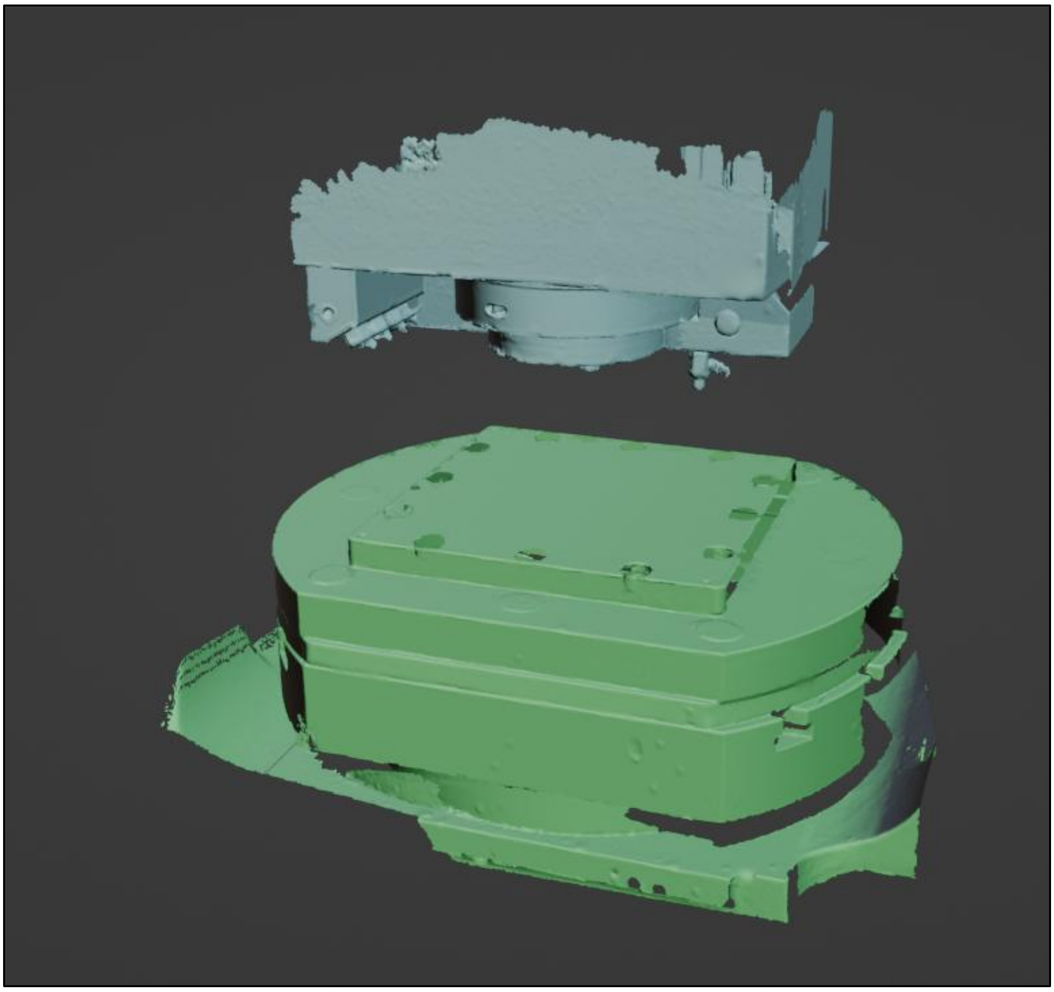


Figure 22 - Scan of Mazak 630M

Figure 23 - Scan of Mazak 630M

While majority of the required geometry has been successfully scanned, the data is far from usable for 3D simulation. As discussed in the section one, the scan data needs to be processed into smooth and uniform models that do not have any 3D scanning inaccuracies. This is why there is a requirement for the reverse engineering to create usable models.

The completed model after reverse engineering and using dimensions given by the machine manufacturer is shown below. The process took approximately 25 hours to create a usable model using Geomagic Design X along side basic dimensions of the components taken with traditional measuring equipment where needed. This process will be discussed in a section three.

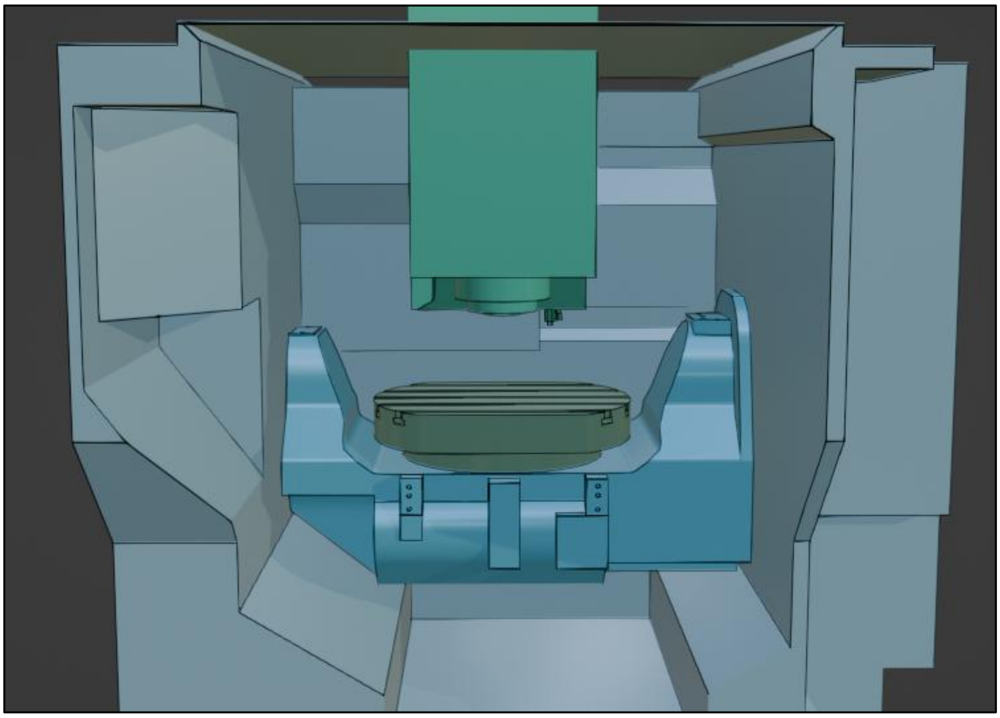


Figure 24 - Final Mazak Model

Figure 25 - Final Mazak Model

At this stage the model is ready to be used in CAM software. This stage is unique to each CAM package, but the general principle is that each independent part of the CNC machine is a separate model which is attached the virtual axis.

As an example, this model is shown in SolidCAM Simulation.

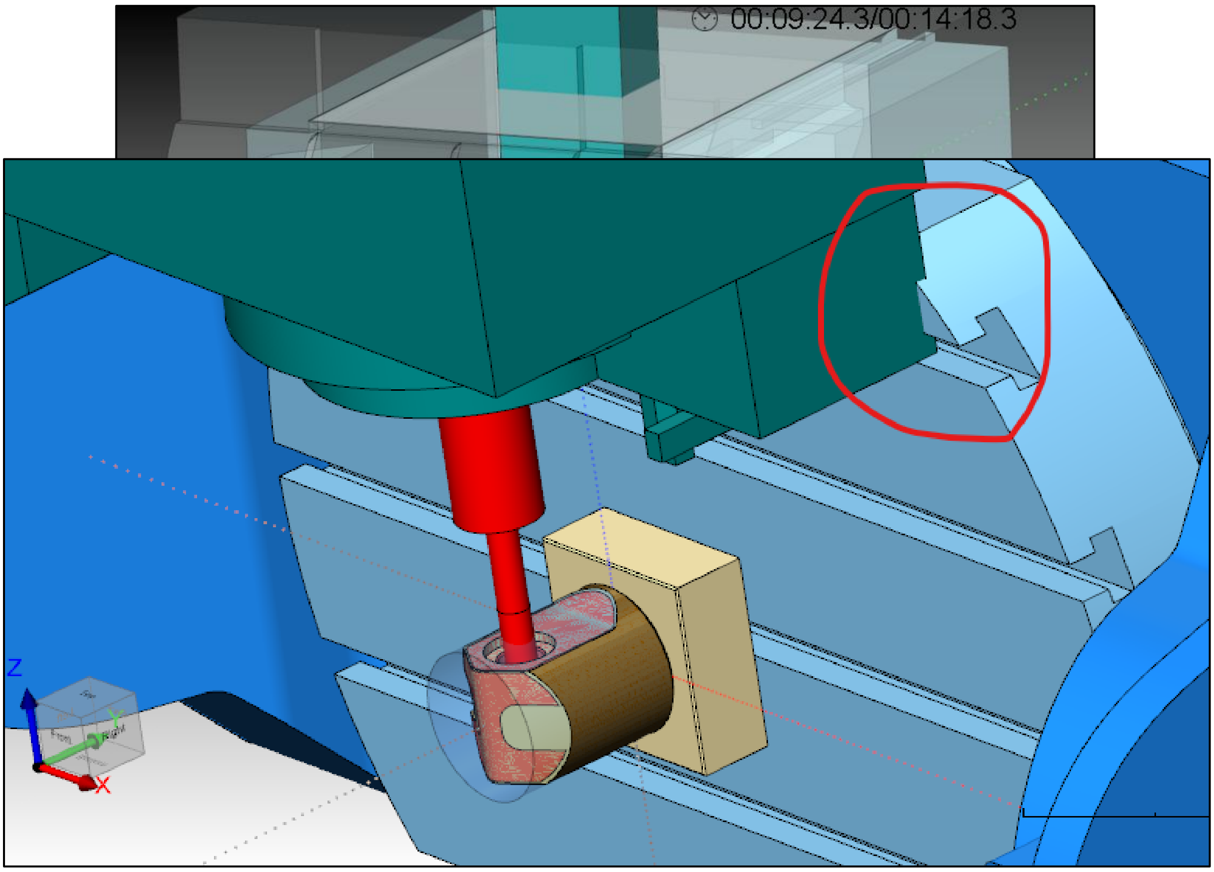


Figure 28 - SolidCAM Collision Detection

Figure 29 - SolidCAM Collision Detection

When using multi-axis toolpaths, collision checking is vital to ensure that the tool head does not collide with the work holding or table. Below shows the collision detection of such a toolpath.

4 Reverse Engineering

To demonstrate the process of reverse engineering a 3D scan, a custom tool holder and welding tool for the Mazak 630M is processed using Geomagic Design X.

4.1 Tool holder for welding tool

The first stage of the process is to align the scan data with the correct axis system.

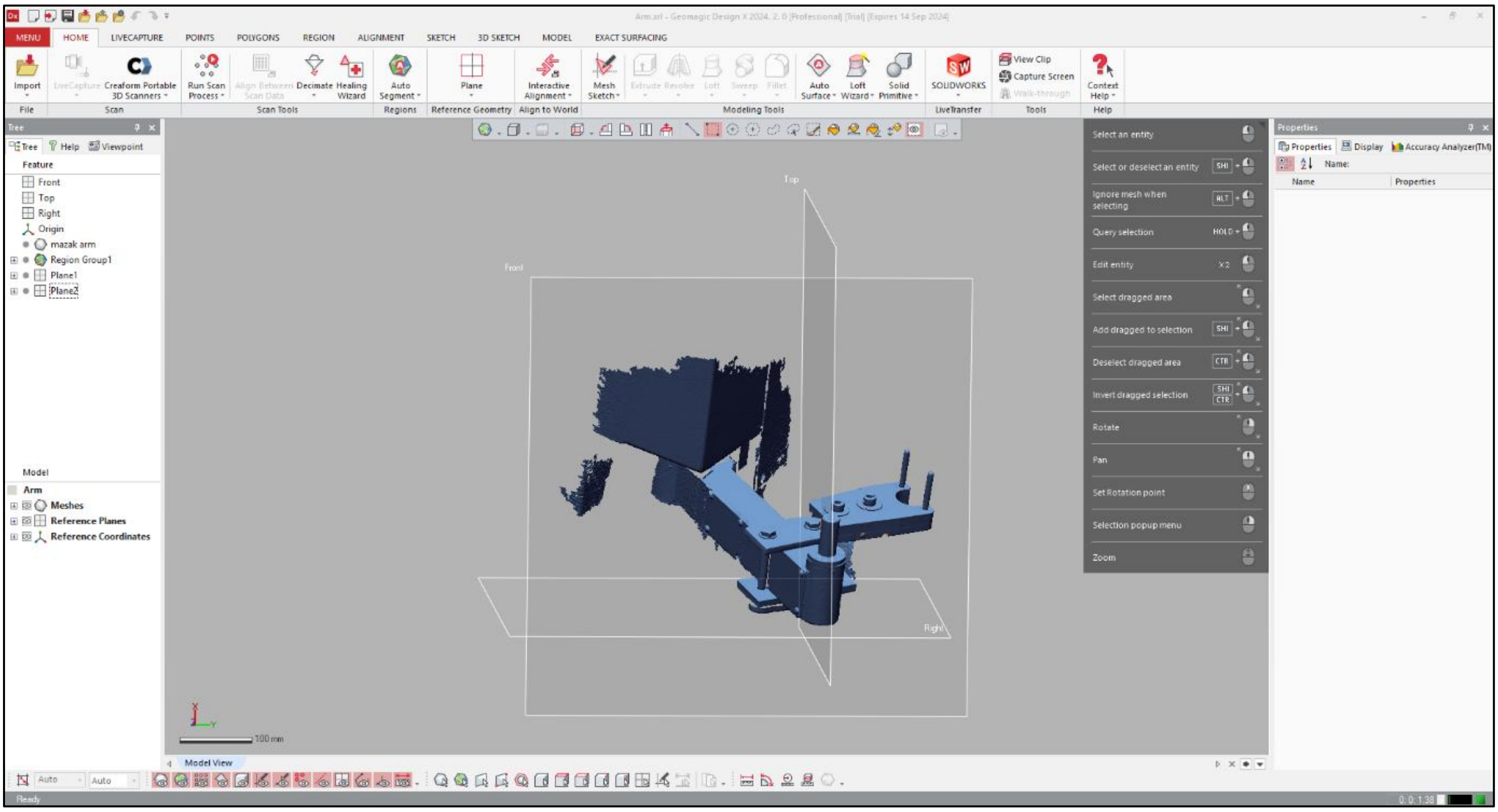


Figure 30 - Geomagic Design X Interface

Figure 31 - Geomagic Design X Interface

Geomagic has an interactive alignment tool that is used to align the scan data with the refence system in Geomagic. The tool first divides the scan into regions that have an acceptable correlation to planes and cylinders. The regions are colour coded for easy reference.

These regions can then be used to define the reference data for scan alignment by selecting the regions that relate to each axis. Because the scan data will not perfectly match all axes, it is important to select the most reliable data for references. The tool will then find the best fitting orientation for the selected data.

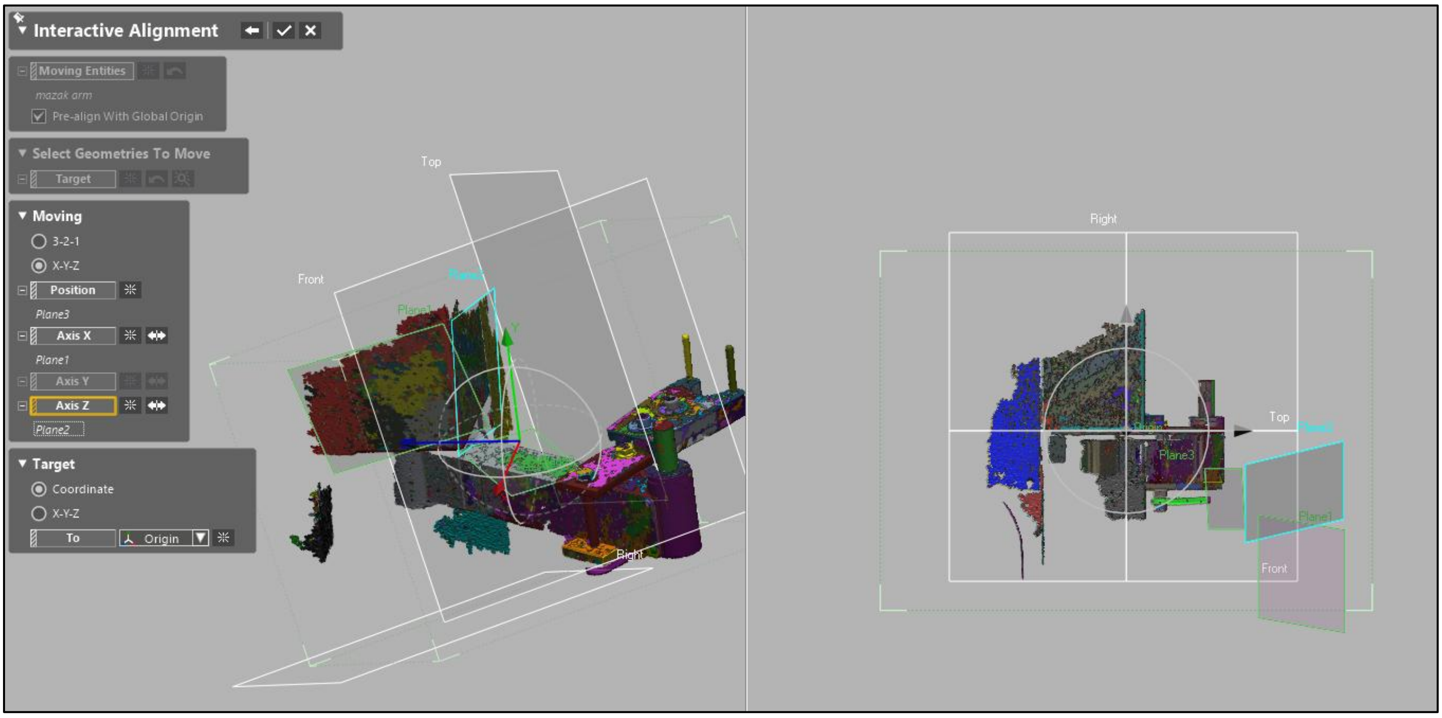


Figure 34 - Geomagic Interactive Alignment

Figure 35 - Geomagic Interactive Alignment

After alignment the regions can be referenced for building up the 3D model. Geomagic has all of the tradition CAD drawing tool such as extrudes and revolves to develop the 3D model. The ability to reference the scan data is what sets it apart from traditional CAD software is the ability to reference the scan data to

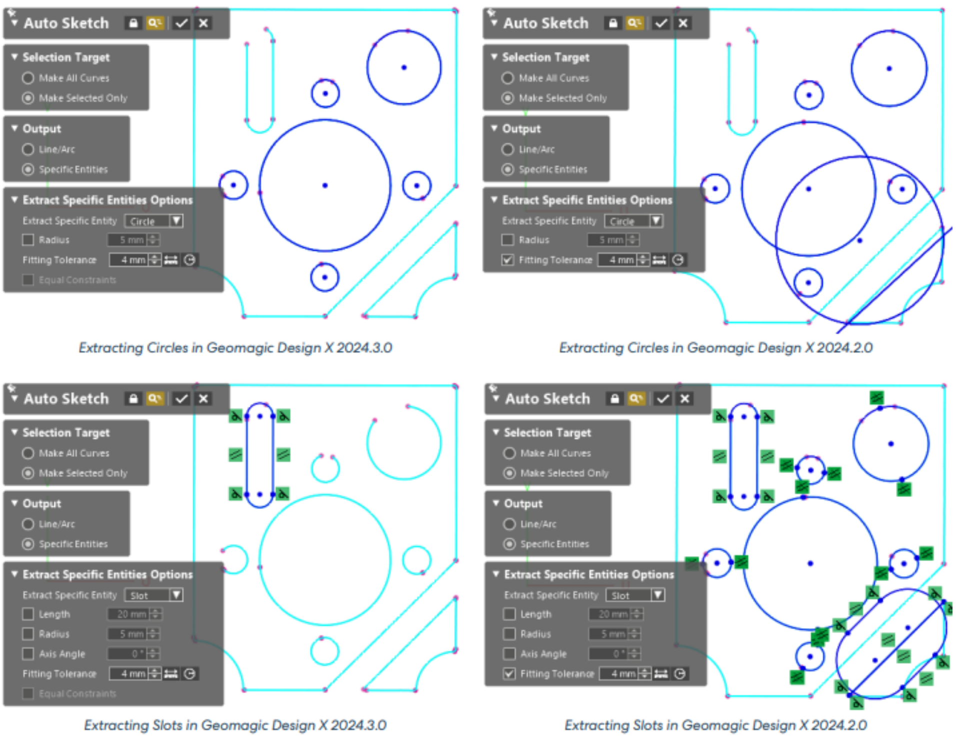
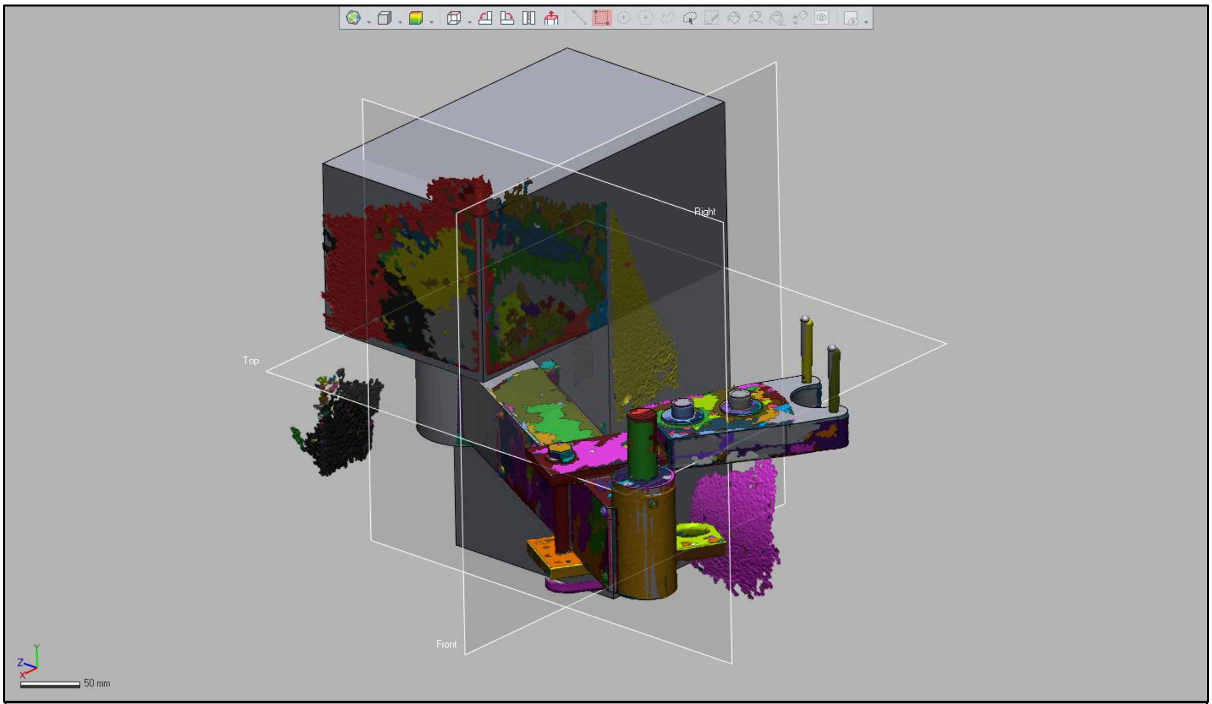


Figure 32 - Geomagic Auto Sketch

Figure 33 - Geomagic Auto Sketch

create the sketches and 3D geometry. The generated regions can be used to create geometric primitives while sketches can make use of planer slices of the mesh. One of Geomagic's tools is an Autosketch function which is able to find and draw constrained sketches given slices of the mesh. These can then be fine tuned before being used to create 3D features.



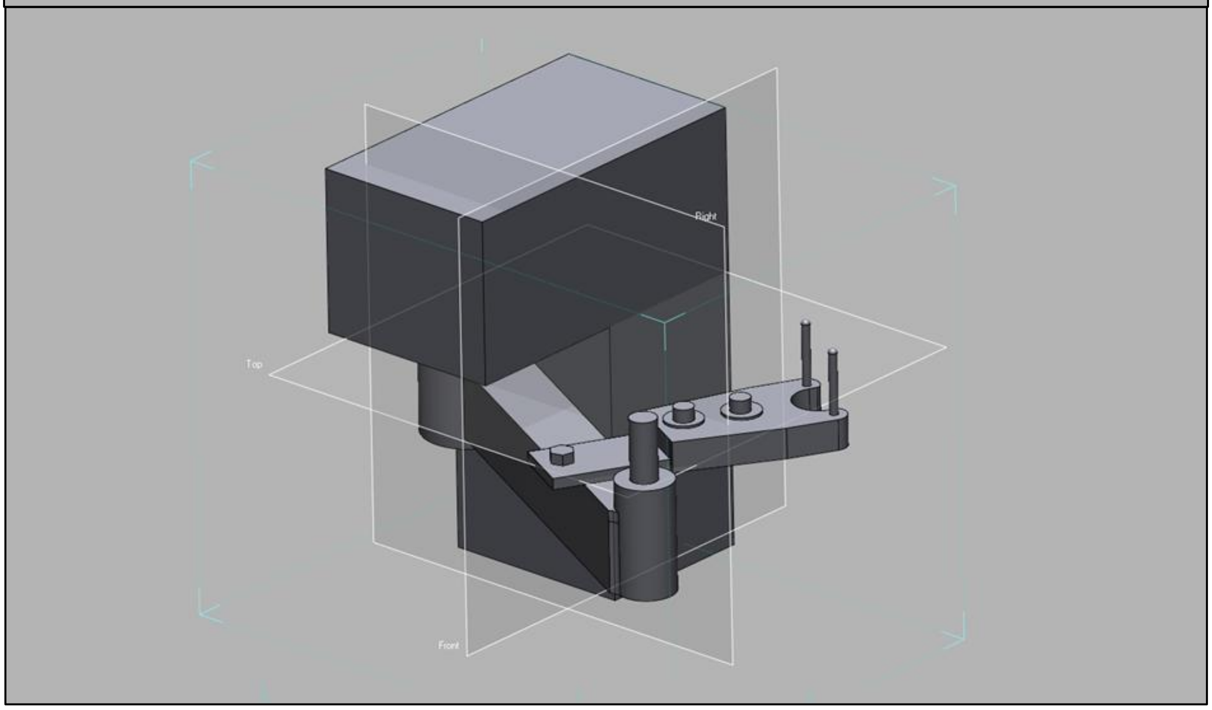


Figure 36 - Reverse Engineered Tool Holder

Figure 37 - Reverse Engineered Tool Holder

Figure 38 – Welding Tool Scan to 3D Model

Figure 39 – Welding Tool Scan to 3D Model

5 Analysis

After completing the remodelling, the new model can be compared with the original 3D scan to analyse the deviation. These deviations will be due 3D scanner inaccuracies and part manufacturing defects while the model has been refined using the average or regions and GD&T relations. Below shows an example of a region where an ideal cylinder was modelled instead of the deformed geometry that was scanned. This can also be used for comparing a casting to the original model. You can investigate warping and other casting errors.

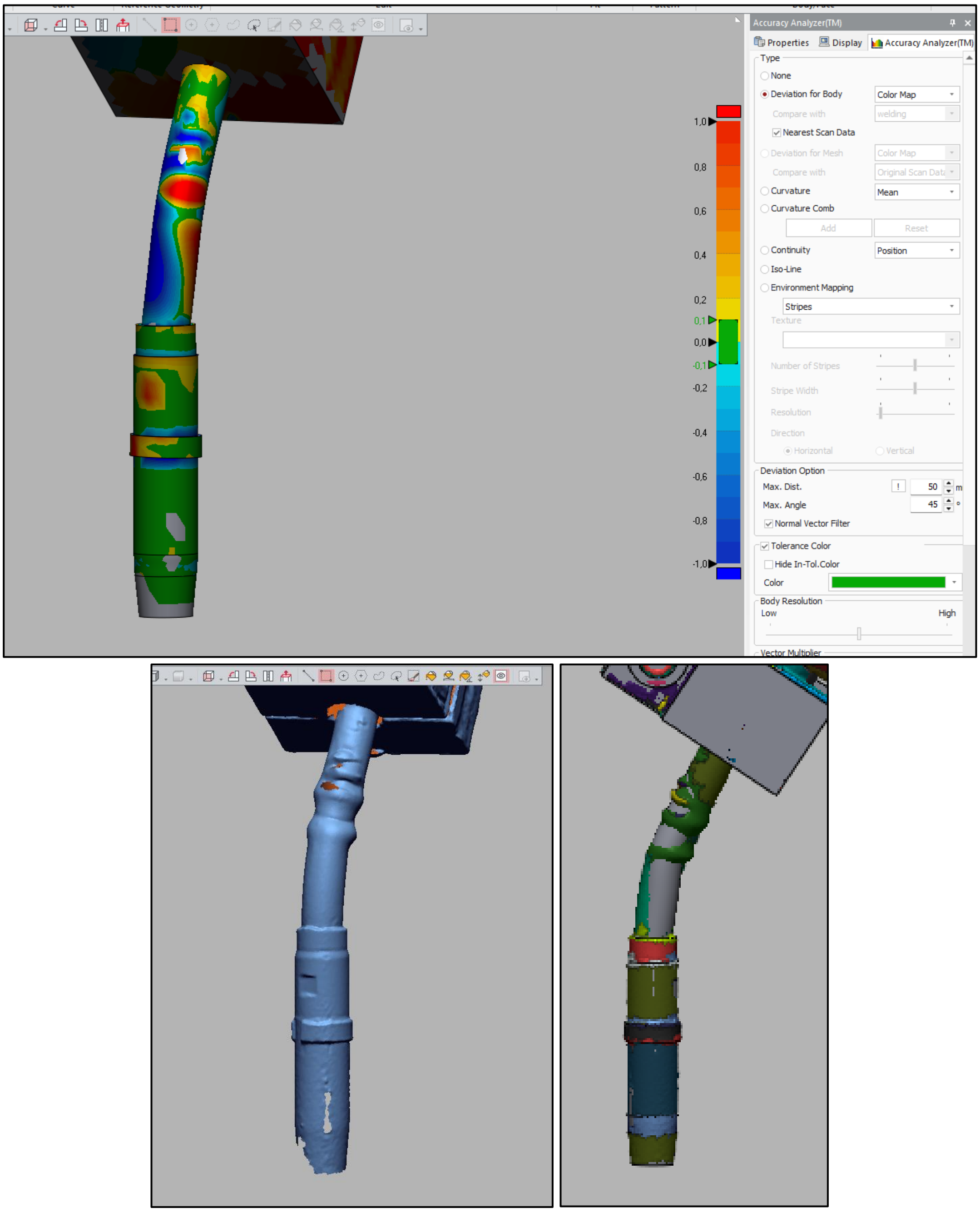


Figure 40 - Deviation Analysis

6 Conclusion

The Einscan Pro 2X paired with a reverse engineering software can be seen to be a powerful tool in the manufacturing environment in both machine simulation and part analysis. Although it is currently limited to smaller objects due to the requirement of scanning markers. If the Einscan colour pack addon was used, the viability to scan larger objects would drastically increase. One such use case would be to go to companies and rapidly scan parts or machines. With a software such as Geomagic Design X or Hexagon Recreate, the scans can be used to do reverse engineering and verification tasks on small and large parts.

References

Einscan, 2018. *EinScan Pro 2X V2.* [Online]

Available at: https://www.einscan.com/handheld-3d-scanner/einscan-pro-2x-v2/

[Accessed 2025].

Einscan, 2021. *Things You Might Not Know About the Align Mode.* [Online]

Available at: https://www.einscan.com/applications/things-you-might-not-know-about-the-align-mode/