Differentiation of 3D scanners and their positioning method when applied to pipeline integrity

Authors : Pierre-Hugues ALLARD, Jérôme-Alexandre LAVOIE

CREAFORM
5825 rue St-Georges, Lévis (QC), Canada, G6V 4L2; Phone: (418) 833-4446
e-mail: pierre-hugues.allard@creaform3d.com, jerome-alexandre.lavoie@creaform3d.com,

Abstract

In the world of 3D scanning, the right scanner depends on the application, but also on the main goal of the people who will use it. Each method has its benefits but also its trade-offs. This paper aims at helping service providers and asset owners select the most suitable 3D scanner solution for their inspection needs.

3D scanners are differentiated according to one of their main features: the positioning method they use. The measuring arm, the tracked 3D scanner, the structured light, and the portable 3D scanner categories will be investigated. More specifically, the two main positioning methods used by portable 3D scanners will be discussed: positioning through targets, and positioning through natural features. A third method called hybrid consists in combining the two. The positioning method is defined as the way a system captures the 3D space and then aligns the data collected during the scanning phase.

3D scanners are used for pipeline fitness-for-service evaluation in replacement of conventional methods such as pit gauge and ultrasound probes. Corrosion and mechanical damage can now be characterized with very high accuracy and repeatability. Each scanner category has been tested for corrosion assessment on a pipeline. We will see how they perform against each other and the importance of a proper positioning method.

1 - Bridging physical and digital worlds

3D scanners are tri-dimensional measurement devices used to capture real-world objects or environments so that they can be remodeled or analyzed in the digital world. The latest generation of 3D scanners do not require contact with the physical object being captured.

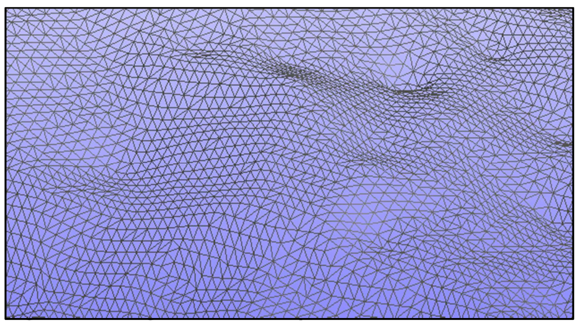
3D scanners can be used to get complete or partial 3D measurements of any physical object. The majority of these devices generate points or measures of extremely high density when compared to traditional “point-by-point” measurement devices.

1.1 - How 3D scanning works

There are two major categories of scanners based on the way they capture data:

- White-light and structured-light systems that take single snapshots/scans
- Scan arms and portable handheld scanners that capture multiple images continuously.

Scanning results are represented using free-form, unstructured three-dimensional data, usually in the form of a point cloud or a triangle mesh. Certain types of scanners also acquire color information for applications where this is important.



Images or scans are brought into a common reference system, where data is merged into a complete model. This process called alignment or registration can be performed during the scan itself, called dynamic referencing, or as a post-processing step.

1.2 - 3D scanning categories and positioning methods

The benefits and limitations of a 3D scanner are typically derived from its positioning method. That's why it is valuable to take a look at positioning methods within the different 3D scanner categories.

1.3 - Measuring arms, portable CMM scanners

CMMs (coordinate measuring machines) and measuring arms can be equipped with either fixed-probe or touch-trigger probe heads. It is also possible to mount a 3D scanning head on a CMM. CMMs with portable arms are positioned using the mechanical encoders integrated in the arm. Many different tools can be mounted on portable CMMs, making it possible to easily integrate scanning and probing in the same project. Portable CMMs need to be fixed on a surface and use a physical link (arm) as their positioning method. This makes them prone to vibrations and other environmental constraints that can affect the performance and

Figure 2: Articulated arm

quality of the result. They also lack flexibility in terms of the locations in which they can be used and the shape of the objects they can scan.

1.4 - Tracked 3D scanners

Optical tracking devices can track various types of measurement tools, including the positioning of a 3D scanner. These scanners use an external optical tracking device to establish positioning. They usually use markers such as passive or active targets that optically bind the tracking device to the scanner. Tracked 3D scanners provide very good accuracy and excellent precision throughout the measurement volume. The optical link is strength of this technology and also one of its limitations. The tracker must always have a clear and direct line of sight to the 3D scanner. Trackers often have a limited working volume. Extending the scanning parameters adds complexity to the process and can induce some additional uncertainty in the measurements. Finally, tracked 3D scanners are usually more expensive than solutions such as portable 3D scanners.

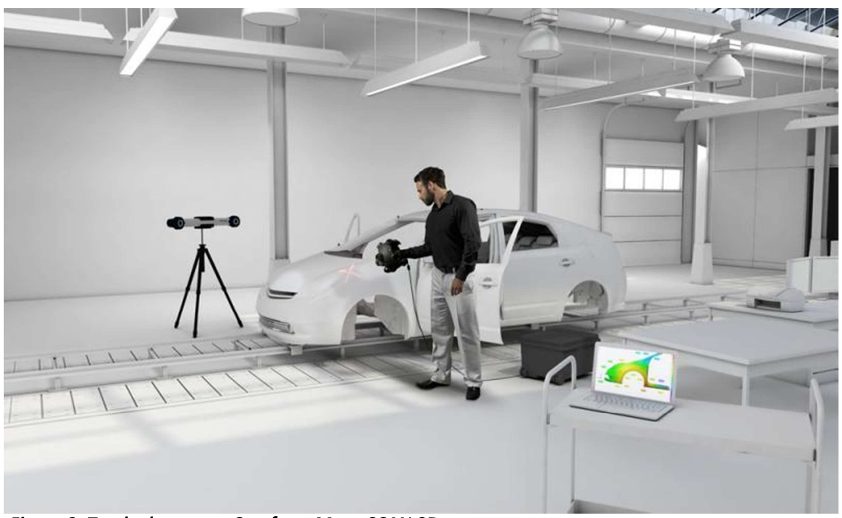


Figure 3: Tracked scanner, Creaform MetraSCAN 3D

1.5 - Structured-light 3D scanners

These scanners project a pattern of light onto a part and process how the pattern is distorted when light hits the object. Either an LCD projector or a scanned or diffracted laser beam projects the light pattern. One, two, or sometimes more sensors record the projected pattern. The positioning method between two pictures taken to perform registration is usually done off line using targets or natural features. If only one camera is used, the position of the projector in relation to the camera must be determined in advance; if two cameras are used, the stereoscopic pair must be calibrated in advance. High-end structured light scanners generate very high-quality data. They typically deliver excellent resolution, which allows for the smallest features on an object to be captured in the results. While white-light scanners can acquire large quantities of data in one scan, overall project speed is not always improved by this methodology. Multiple scans are required in most cases to cover all angles on more complex parts, which is very time-consuming.

Figure 4: White-light scanner pattern projection

1.6 - Portable 3D scanners

Many types of portable 3D scanners are available on the market today, principally using laser-line or white-light technologies. Laser scanners project one or many laser lines on an object while white-light devices project a light and shade pattern. Both will analyze the resulting deformed projections to extract the 3D data. Handheld scanners rely on two cameras to create what is called stereoscopic vision. This enables the device to determine the scanner position in relation to specific points, which could be positioning targets, the object's natural features or textures. Some newer portable scanners use a mix of positioning types called hybrid positioning.

Portable 3D scanners can be transported with minimum effort and are often easier to use than other scanner types. They can combine multiple positioning methods, providing the accuracy of positioning targets with the flexibility of object features and texture positioning. The most advanced technologies can acquire more than half-a-million points per second and rebuild the 3D triangle mesh live during the scanning process. Handheld scanners do not require a mechanical link or a direct line of sight with a tracker. This enables them to reach narrow and enclosed areas.

Portable scanners use self-positioning on a more local area, which means that errors can stack up as the scanning volume grows. It is possible to circumvent this by using technologies such as photogrammetry and positioning targets to minimize errors, but these additional steps might increase setup time and limit the size of the objects or areas that can be scanned efficiently.

Figure 5: Creaform portable scanner HandySCAN 700

2 - Big performance in small packages

The knock on portable 3D scanning systems used to be that they couldn't match the performance of their hulking big brothers. That might have been true even five years ago, but it isn't any longer.

Consider these specifications for the newest generation of hand-held scanners:

- Accuracy up to 0.030 mm (0.0011in)
- Resolution up to 0.050 mm (0.0020in)
- Scanning speed of up to 550,000 measures per second
- Weight of less than three pounds
- True portability in the field or the shop
- Stability in environments where vibration is the norm.

This combination of speed, accuracy, portability and ease-of-use has been delivered through a series of technological breakthroughs, the biggest of which is self-positioning. Scanners can now rely on the object being scanned as the reference for positioning. This is as opposed to using an external positioning device such as an arm, CMM or tracker.

True portability means being able to comfortably transport a 3D scanning system to remote locations and operate in tight spaces and unstable environments. But it also means having the flexibility to accomplish multiple types of tasks within a dedicated room or for outside field work. Beyond the ability to take a 3D scanner anywhere, portability has the advantage of flexibility: optimizing a 3D scanning investment, as it enables users to accomplish a wide range of scanning tasks with a single, transportable system. The greater variety of objects you can scan and the greater number of places in which you can scan, the greater the return on investment.

3 - Positioning methods for portable 3D scanners

Different positioning methods used by portables scanners can have an important impact on performance and usability. In the sections that follow, we'll explore the two main positioning methods for portable 3D scanners positioning through targets and positioning through natural features (geometry), as well as a third method that is a blending of the two. At the end, readers should have a good idea about what type of positioning system best aligns with your 3D scanning needs.

3.1 - Positioning through targets

In this method, positioning targets are applied before scanning, either on the object or around its immediate surroundings in the case of a very small pipe, for example. The targets enable users to register all the different camera frames for the 3D data sets acquired by the scanner. Targets usually have a simple geometric shape, often a circle, and are specifically designed for easy detection by the 3D scanner's optical components.

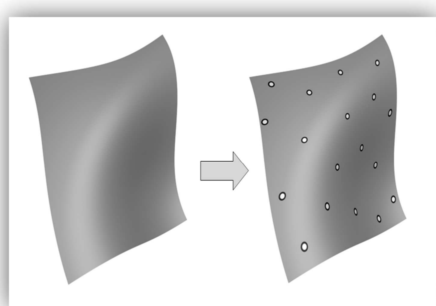


Figure 6: Positioning targets installation

Before scanning, there is a process called pre-modeling to obtain a dedicated algorithm and a preliminary descriptor for the object being scanned. These two items make target detection easier and more accurate. After the scanner detects targets individually, the next step determines their relative position and. A target data set with a minimum of three targets is used to position the scanning frame. As the scanner is moved around the part, new targets are detected and registered on the global positioning model. Positioning through targets allows data to be acquired separately from the scan object's surface. It also allows users to acquire data with complementary technologies, which can save time and enable portable 3D scanners to be used for a wider range of projects.

Positioning through targets is the only method that enables portable 3D scanners to deliver metrology-grade quality, which in the past was restricted to measurement arm scanners and stationary structured-light 3D scanners in dedicated measurement rooms.

3.2 - Positioning by geometry with natural features

This method uses the object's inherent characteristics -- its shape and texture attributes -- to record object positioning. As data is acquired, the scanner will detect some shapes and textures on the scanned area and register them for future use. When analyzing each new frame, detected features will be compared with previously registered ones to match up the images and help determine the scan object's position. A scanner must have strong self-positioning capabilities and built-in intelligence to position itself using natural features. Refining the registration or correcting a frame requires anticipating the next frame in real time. The natural features of the scan object must be prominent enough to be detected accurately by the scanner. The density of the data for a single frame must also be high enough for it to extract data.

While this method is flexible and may seem to speed the time required for a project, there are important aspects that must be taken into account. Unlike positioning targets, natural features vary from one object to another. The resulting precision and accuracy can be greatly affected by the type of objects being scanned. Most objects include at least some surfaces with few defining details. This affects the accuracy of the scan results. Cylindrical shapes usually don't offer enough geometry to lock all 6 degrees of freedom. Rotations around the pipe axis as well as the translations along the pipe are difficult to lock accurately.

3.3 - Hybrid positioning

It is possible to combine target and natural positioning into a hybrid positioning mode. Users can compensate for the lack of natural features in a given object or specific areas by adding positioning targets.

Although hybrid positioning would appear to be the best of both worlds, it will not generate metrology-grade results: Users can never be completely certain that they are covering every area that needs to be covered in order to ensure the type of absolute accuracy of scanning with positioning targets.

4 - Matching 3D scanning needs to positioning methods

The ultimate question remains: What's the right 3D scanner for my needs?

If your main goal is speed and simplicity, a 3D scanner using the **natural features positioning method** is probably right for you. The trade-offs are lower accuracy and possible lack of natural features on the scan object, which can mean increased time spent modeling and making corrections.

If your application requires flexibility, but not high accuracy or metrology-grade resolution, the **hybrid positioning method** is the best solution. These 3D scanners are perfectly suited for scanning applications such as industrial product development, where absolute precision is not required.

Some applications require a level of precision or resolution (details) that scanners using the hybrid positioning method cannot match. For these applications, using a high-range portable scanner with **positioning targets** is recommended.

The following table presents a simplified comparison:

Main Goal	Positioning Methods	Main Limitation(s)
Speed, Simplicity	Geometry (Natural Features)	Precision, features and performance depend on the object
Flexibility	Geometry + Targets (Hybrid)	Compromise on accuracy
Reliability, precision	Targets	Affixing targets on the object

Table 1: Summary of positioning methods

5 - Case Study: Analyzing External Corrosion

This section presents the results for external corrosion assessment for portable scanners using the following positioning methods: natural features, hybrid positioning and using targets. In parallel, the impact of not having any positioning method will be studied. The equipment used for this experimentation was two different structured-light scanners and a laser-based scanner. All gathered data were compared the results acquired from Mitutoyo Crysta-ApexS CMM mounted with a Kreon KZ50 optical head. The positioning of the CMM has an uncertainty of 0.0127 mm (0.0005 in) and the KZ50 specifies between 0.0127mm (0.0005 in) and 0.0254 mm (0.001 in). To insure the best correlation between results extracted from all scanners positioning methods, the same software platform was used to analyze all data. Here is the part used for the case study:

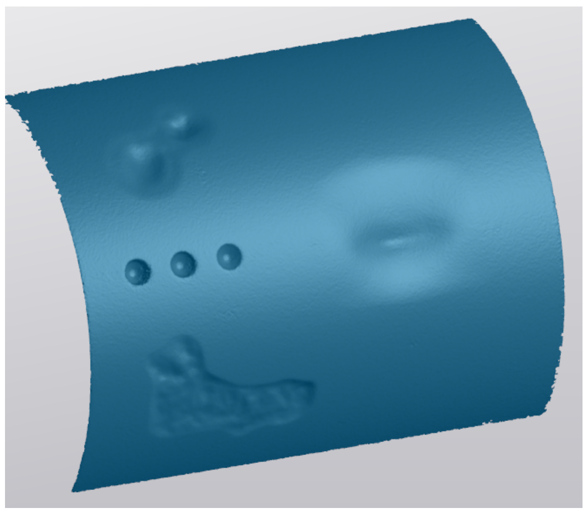


Figure 7: Part used for this study

Phase 1: Positioning Methods Comparison

The first portion of the study was completed by using a structured light scanner positioned by natural features. Then targets were added to the part to test the hybrid positioning and finally the laser-based system was used. The laser-based scanner positioning method used only the targets. Another structured-light system was used without using any positioning method. Finally manual measurements using a pit gauge were also taken. This study focus only on the maximum depths found for different corrosion features. Here is the summary table:

	Positioning Methods					
	CMM	Natural Features	Hybrid	Targets	None	Pit Gauge
Feature 1	**8.146**	8.094	8.201	**8.147**	8.572	8.15
Feature 2	**2.916**	2.903	2.922	**2.926**	3.656	2.89
Feature 3	**4.203**	4.232	4.162	**4.241**	5.890	4.23
Feature 4	**3.607**	3.565	3.546	**3.626**	4.025	3.61
Feature 5	**4.590**	4.554	4.521	**4.602**	5.052	4.62
Feature 6	**5.588**	5.500	5.510	**5.623**	6.094	5.61

Table 2: Maximum depths measurements using different positioning methods

The comparison clearly show that using targets as positioning method for portable scanners is the only way of getting metrology-grade results. The differences between the laser-based system and the CMM are all within 0.035 mm (0.0015 in). Natural features method seems to deliver an interesting level of accuracy compared to not having any positioning method. In this specific case both natural features and hybrid positioning methods delivers similar results.

	Positioning Methods				
	CMM	**Natural Features**	**CMM vs NF**	**Hybrid**	**CMM vs Hybrid**
Feature 1	**8.146**	8.094	0.052	8.201	-0.055
Feature 2	**2.916**	2.903	0.013	2.922	-0.006
Feature 3	**4.203**	4.232	-0.029	4.162	0.041
Feature 4	**3.607**	3.565	0.042	3.546	0.061
Feature 5	**4.590**	4.554	0.036	4.521	0.069
Feature 6	**5.588**	5.500	0.088	5.510	0.078

Table 3: Comparison between Natural Features positioning method and Hybrid positioning method

Phase 2: Texture Projection vs Raw Point Cloud

In the course of this study, we found interesting that the structured-light scanner used without positioning method projects the texture (color) on the acquired point cloud. Although the 3D picture looked good, the raw point cloud was noisy and once processed in the analysis software, found to be inaccurate (as demonstrated above).

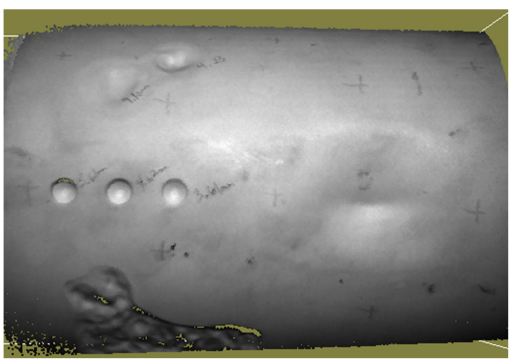


Figure 8a: Point cloud with texture projected on it

Figure 8b: Raw point cloud

Such noise in raw data point cloud can be explained either by a system wrongly calibrated or the incapacity to compensate for vibrations during data acquisition. However, the manufacturer of the device used during our study claims that his system never needs calibration other than the factory calibration. In fact, the system used is rated IP 67 to meet the need of operating the system in harsh environments. This seems to confirm the importance of having a positioning method to generate results with a high level of accuracy.

Phase 3: Impact of Pictures Registration

To push further our analysis of this system and simulate a real inspection case, we took multiple pictures in different orientation to cover all angles. The registration of these pictures was not done automatically since the native acquisition software did not allow it. We were required to manually align the pictures based on natural features. We do not know for sure if the software used the geometry to complete our manual alignment. The table below show the results obtained before and after the registration.

	CMM	Picture 1	Pictures 1-2-3 Merged
Feature 1	**8.146**	8.572	9.035
Feature 2	**2.916**	3.656	3.368
Feature 3	**4.203**	5.890	5.371
Feature 4	**3.607**	4.025	4.299
Feature 5	**4.590**	5.052	5.419
Feature 6	**5.588**	6.094	5.887

Table 3: Impact of images registration on accuracy

The impact of the registration is clearly visible on the accuracy of the measurement. We have done the best registration possible using all of our expertise working with 3D measuring devices. Large variations were found between results got from the first picture and the ones gathered after the manual alignment. Merging operations were painful and time consuming.

Conclusion

Using positioning targets is the best method to delivers accurate results. One of the structured-light and the laser-based systems used during this study offered different positioning method for different results. They both had real time registration of the data which made the analysis faster and easier.