Surface indication measurement

Using the remote visual inspection non-destructive evaluation method for surface indication measurement precision and accuracy

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A video borescope can meet your advanced measurement needs using the Remote Visual Inspection (RVI) non-destructive evaluation (NDE) method. This paper will answer many of your questions about measurement precision and accuracy, including:

- What is the smallest error that can be expected under optimal conditions with Waygate Technologies Real3D™ Stereo & Real3D™ Phase measurement?
- Which is better—Real3D Stereo or Real3D Phase structured light?
- Can Real3D measure on your specific surfaces?
- How small of an indication can be measured and with what precision and accuracy?
- What is MTD and does it affect accuracy?
- Does "measurement performance" differ between the various Optical Tip Adapter options?
- How do the various measurement types affect measurement uncertainty?

For further details on this topic, the Waygate Technologies' Real3D™ Measurement Handbook is an excellent resource.

The intent of this paper is to better help one understand advanced measurement technology with a video borescope and achieve the answers to the questions above on the items, assets, areas of interest one is considering measuring various surface indications upon using the Remote Visual Inspection (RVI) NDE method.

For detailed reference on measurement types and best practices, please consult the Real3D Measurement Handbook.

Making the right decision

When making safety-of-flight or Fit for Service/continued operation decisions, you likely will need to accurately determine the size, area, or depth of an indication, the amount of missing material, or a blade tip clearance. Waygate Technologies' Real3D Measurement technology provides the quality data you need to help you make the best possible decision.

Unmatched and unavailable in any other video borescope, Waygate's Mentor Visual iQ VideoProbe™ has 1.2 mega-pixel imaging and patented 3D structured light measurement with a fully surfaced point cloud.

The reliable, precise, and accurate Mentor Visual iQ can save significant time and millions of dollars by uncovering component flaws before they become a serious problem. In addition, it can generate a detailed catalog of component degradation, thereby affecting subsequent component design considerations.

For reference, eight measurement types are available on the flame-colored Mentor Visual iQ VideoProbe:

- Length
- Point to line
- Depth
- Area
- Multi-segment
- Depth profile
- Area depth profile
- Blade tip clearance

Several of the above-mentioned types can be assisted by Measurement Plane which allows for measurements using a mathematical plane. If any of these measurement types is sequentially repeated during an inspection event, enabling the Auto Repeat feature decreases the measurement setup time each time a measurement image is captured.

A VideoProbe from Waygate Technologies may support various measurement technologies including Shadow, traditional Stereo, Real3D Stereo and Real3D Phase. Whether you choose one of these technologies, or one offered by another supplier, there is only one correct answer to questions regarding achievable precision and accuracy: **It depends!**

What you need to know

Many application-dependent factors impact the accuracy of Stereo, Real3D Stereo, and Real3D Phase measurements. These factors include:

- **Measurement data viability**
  - Real3D Phase Measurement (3DPM) generates a plurality of XYZ points using structured light fringe patterns projected on a surface. These are then processed in an algorithm that generates a fully surfaced point cloud representing points on a surface to be measured. The white light image can be out of focus and a viable XYZ data set still may be generated.
  - Stereo and Real3D Stereo measurement work on the principle of matching pixels in stereoscopic images using a 3D coordinate system. Cursor placement in both images is critical; they must both be on the same pixel to obtain meaningful results. Thus, the image to be analyzed with either measurement type must be in sharp focus.

- **Tip-to-target distance**
  All current 3D measuring borescope systems rely on triangulation. As the tip-to-target distance increases, the accuracy of the computed 3D surface points decreases. Thus, measurements made with the borescope tip close to the surface generally will be more accurate than measurements made from farther away.

  This is especially true of all depth-type measurements. Real3D measurement technologies provide a Maximum Target Distance (MTD) value, indicating the distance from the measurement tip adapter to the viewed surface at the location of the farthest cursor in a measurement, and advise the user when the MTD is excessive for that measurement type and size.
- **Incident angle**
  The angular relationship between the probe tip and the target feature can have a profound effect on the resultant measurement calculation. Try to avoid situations where this angle exceeds approximately 60 degrees. Re-adjust the probe or perhaps the target component if possible. If circumstances prevent both possibilities, then consider using an alternative measurement tip such as the forward or side-facing option.
- **Surface conditions**
  Shiny surfaces often result in glare and/or dark images that make it difficult for systems to accurately determine 3D surface coordinates. Smooth surfaces with little texture may be problematic for stereo systems, which rely on differentiating surface detail to determine 3D surface data. Oily, transparent, or translucent surfaces also can be challenging.
- **Reflections**
  Polished surfaces such as shiny turbine compressor blades and shrouds or high-purity piping may reflect mirror images of other parts/areas or cause projected patterns to bounce between different surfaces, making it difficult for systems to determine accurate 3D surface points.
- **Aspect ratio**
  Systems may be unable to both view and illuminate the bottom of narrow, deep features with either structured light patterns or normal illumination, making them unable to determine accurate 3D data at the bottom of such features.

Through proper training, RVI inspectors who must perform measurements can learn how to:

- Choose the most appropriate measurement technology, optical tip adapter, and measurement type for a given application.
- Position the probe tip to maximize the fidelity of the 3D surface data generated by the system and used to compute measurement results.
- Place cursors at the correct locations on an indication in the image to obtain the desired dimensions.
- Leverage the 3D Surface Mask and fully surfaced 3D point cloud view to evaluate 3D data quality and correctness of cursor placement when using Real3D Stereo or Real3D Phase.

Given the above factors and variability in inspector skill levels, the best way for an organization to establish expected precision and accuracy on any given surface type and/or expected indication type is to do a Gage Repeatability and Reproducibility (R&R) study on a part that is representative of the actual inspection requirement. The inspectors doing the R&R study should have similar skill levels as those who will be performing the actual measurements.

The American Quality Society (AQS) has a description of that process on its website.

On precision and accuracy

The Real3D™ Measurement Handbook provides detailed information on Real3D measurement technologies including accuracy curves, which were developed through a study performed by a third party. These represent the technologies' capability when used by a well-trained inspector under ideal conditions.

The Mentor Visual iQ displays measurement results with a precision of 0.01 mm (0.0004”) in mm mode or 0.001” (0.0254 mm) in inch mode. While all displayed digits may be significant on small measurements made from very small tip-to-target distances, the right-most digits may not be meaningful on measurements made from larger distances.

Keep in mind that measuring in millimeters allows for a more precise value:

- 0.0100 mm = 0.0004”
- 0.0254 mm = 0.0010”

The Mentor Visual iQ shows two decimal points in mm (x.xxmm) and three decimals in inches (x.xxx”).

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Under ideal conditions, and for several indication types and sizes, the relationship between expected measurement accuracy at a given MTD is published in the Measurement Data Accuracy section of the Real3D™ Measurement Handbook.

While a lower MTD is desirable, neither a high nor low MTD ensures the captured measurement data is viable. MTD is a data point providing more information for the analysis process.

For example, see Figures 1 and 2 from a third party’s Gage R&R study, as seen in the Real3D™ Measurement Handbook.

It is recommended that 0.125mm (0.005”) be considered the minimum feature size for measurement.

Under ideal conditions, a general guideline to consider when measuring these smaller features is that Real3D Phase and Real3D Stereo measurement usually can achieve errors in the +/- 0.05mm (+/- 0.002”) range or better on both length and depth type measurements.

Caution: This does not express or imply that you will be able to achieve these results for all measurements attempted. A Gage R&R study will determine expected results for any given measurement requirements using a VideoProbe.

Ideal conditions vary by measurement technology as described below.

Real3D Phase Measurement ideal conditions

- Measurements by a trained, qualified RVI technician
- Clean and calibrated optical tip adapters (OTAs) and camera lens
- Camera positioned very close to the indication, even if slightly out of focus
- Camera positioned in a non-perpendicular incident angle to the surface
- Measurement upon a matte, non-reflective surface finish
- Minimal or eliminated reflections and shadows of structured light
- Absence of ambient light
- Systems may be unable to both view and illuminate the bottom of narrow, deep features with either structured light patterns or normal illumination, making them unable to determine accurate 3D data at the bottom of such features.

Real3D Stereo and Stereo Measurement ideal conditions:

- Measurements by a trained, qualified RVI technician
- Clean and calibrated OTAs and camera lens
- Camera positioned very close to the indication, and in sharp focus
- Measurement on surfaces that are feature-rich and not bland
- No glare on the indication
- Pixel pattern differentiation around the indication

While a lower MTD is desirable, neither a high nor low MTD ensures the captured measurement data is viable. MTD is a data point providing more information for the analysis process.

For example, see Figures 1 and 2 from a third party's Gage R&R study, as seen in the Real3D™ Measurement Handbook.

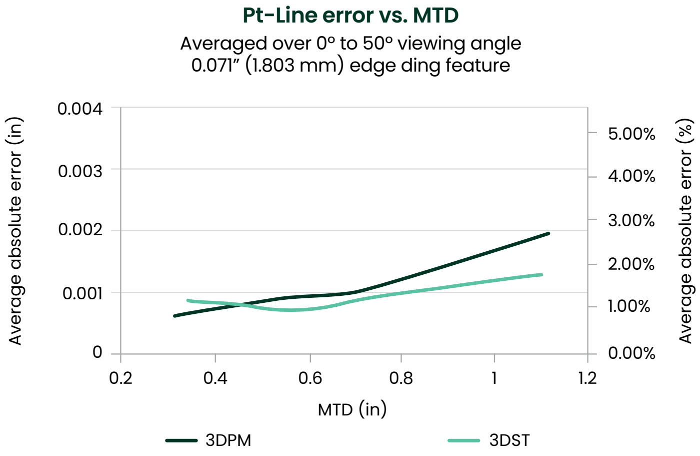

Figure 1

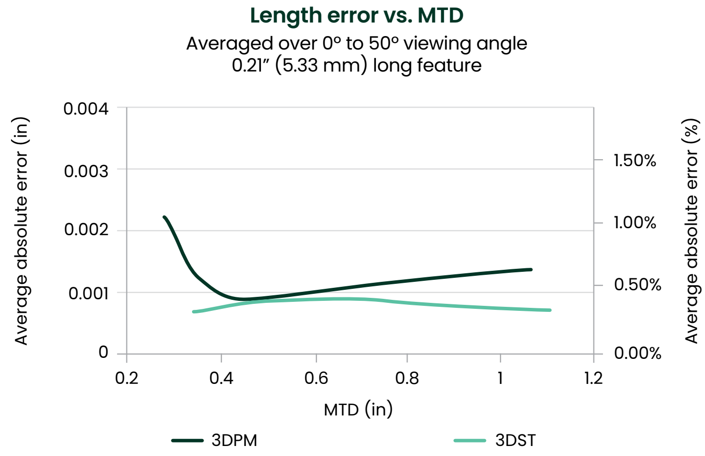

Figure 2

Note that in Figure 1, a lower MTD yielded a lower Average Absolute Error for 3DPM. However, in Figure 2, a lower MTD did not yield a lower Average Absolute Error for 3DPM.

In addition, increasing MTD has a much greater effect on depth measurement types than it does on length or area types. This is because the Z value of a given pixel becomes more difficult to calculate as the tip-to-target distance increases (greater MTDs). The main reason: A pixel on an imager has differing X and Y values based on a given Z (MTD) value and the actual size of the imager's pixels.

Additionally, precision and accuracy of an indication's measurement values are affected by several variables, one of which is MTD. Another is interpreting the surface and not having measurements tilted to the desired plane.

This is where the value of a fully surfaced 3D point cloud is a phenomenal analysis tool in Real3D measurement. See Images 1 and 2 below as an example.

Image 1 is a typical view of a traditional stereo measurement. In this case, the blade tip clearance—a jet engine's turbine blade clearance to the shroud—is being measured. Using a Depth measurement, three selected points establish a mathematical reference plane on the shroud. The distance (clearance) from the tip of the blade to the Depth plane on the shroud is shown as 1.24mm (0.049").

The goal is to place a cursor on the left image, and the processor must precisely match the same pixel on the right image.

Many qualified technicians have looked at this image and have said it exhibits good technique.

Image 1

Image 2

Image 2 depicts this same image using the Real3D Stereo Measurements' fully surfaced point cloud in the right half of the image. Obviously, based on cursor placement, this measurement is both very accurate and very wrong! One of the Depth reference plane's cursors is on the blade and not on the shroud with the other two cursors. The results are that the measurement plane is tilted to the shroud yielding a gross error. In this case, it could lead to a $1 million-plus engine removal and replacement—or worse.

In Image 3, when the errant cursor is moved, in either the white light image or the point cloud and from the blade to the shroud, all three cursors of the Depth reference plane are on the shroud. In addition, the shroud is now aligned with the reference plane (the dark blue square frame around the point cloud data), and the depth cursor (fuscia colored) is on the blade tip and now perpendicular to the Depth plane and shroud. The result is now 1.56mm, a significant difference of 0.32mm (0.013"). Also, note that all pixels on the shroud that are very close to the Depth plane are now masked in green.

Image 3

Summary

Many factors can affect the precision and accuracy of measurements in each application. Training is critical to making reliable measurements. While we can provide guidelines and accuracy curves that reflect system capability under ideal conditions, those guidelines/curves may not represent achievable accuracy under different conditions at your site. We therefore recommend that trained and qualified inspectors/technicians perform a Gage R&R study for critical applications.

The Mentor Visual iQ Ø6.1mm system with Real3D Stereo measurement and Real3D Phase measurement using structured light has been evaluated by a third party using a Gage R&R process. The results are published in the Real3D™ Measurement Handbook.

Real3D measurement, both Stereo and Phase structured light, has proved to have excellent precision and accuracy in hundreds of applications globally in aerospace, power generation, petrochemical and general manufacturing.

Enhanced precision of measurement results is enhanced by choosing a Ø6.1mm or Ø8.4mm Mentor Visual iQ VideoProbe with 1.2 mega-pixel high definition (HD) cameras. In some applications, this allows inspectors to place cursors more precisely on an indication in a measurement image.

Since the measurement technologies and types are the same for standard definition (SD) and high definition (HD) cameras, accuracy is expected to be about the same.

Finally, do not overlook the importance of trained and qualified inspectors performing any Non-Destructive Inspection or testing method, including Real3D measurement with a VideoProbe, or any measuring video borescope. A trained and qualified RVI inspector should achieve the best possible results on a given surface for a given indication type.

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