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CAD-TO-SCAN PLANNING FOR HYBRID MANUFACTURING

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Abstract

The University of Tennessee, Knoxville (UT) has developed a hybrid manufacturing work cell incorporating wire-arc additive manufacturing (WAAM), fringe projection scanning and 5-axis machining. Integrating metrology into the hybrid manufacturing work cell enables optimization of printed part placement for machining and/or supplementary material, when necessary, via additional deposition. This presentation will explore path planning for efficient imaging of printed geometries. The acquired scans are then polygonized and compared to the desired geometry which is utilized in defining machining areas with excess material or underbuilt areas for additional material deposition via gas metal arc welding (GMAW).

Introduction

A current challenge with three-dimensional scanning of complex WAAM printed geometries is the visibility of every feature and surface of the geometry. Current static configurations of scanners inhibit full discernibility of an entire part. Current research is evaluating part positioner angles and positions that create the most ideal configurations for scan images. In this paper, a three-blade geometry is scanned and analyzed using a ZEISS GOM ATOS Q fringe projection scanner. The ATOS Q is mounted to an overhead fixture that can translate laterally and vertically for generating desired scan trajectories. The part positioner is rotated and tilted for the scanning process to optimize the field of view of the scanner for part geometry. Generation of the requisite scan path and imaging sequence is non-trivial, however, as obscurations of the part geometry and surface features, particularly printed layer beads, introduce challenges leading to redundant scan areas and a prohibitively large number of scans. Quality scans are characteristically easier to produce via manual, handheld scanning but are substantially more labor and time intensive.

Hybrid Cell Process

UT's hybrid cell begins by using a Kuka KR50 welding robot with a coupled part positioner to print a part geometry onto a pallet mounted to a KP-2 rotary-tilt part positioner. The part, pallet and tilt stage are translated on a KL4000 linear positioner to the metrology area of the workcell for scanning. The GOM ATOS Q scanner incrementally scans across the part surfaces, scans that are then stitched together in GOM Inspect to create a 3-dimensional point cloud. This point cloud can then be converted into a water-tight STL CAD model. The scanned geometry is then compared to a CAD model of the intended geometry and is used to inform the machining process of overbuilt areas in need of machining, or underbuilt areas in need of additional deposition. The part and pallet can then be translated back to the KR-50 for additional printing or can be transported into a five-axis Haas UMC-750 machining center via a Kuka KR250 robot. Post-machining, the part can be returned to the metrology area to be re-scanned by the ATOS Q. The secondary scan informs the cell of any additional deposition or machining required and the process can be repeated until the final comparison is within tolerances when compared to the desired geometry.

Scanner Operation

The GOM ATOS Q scanner works by fringe projecting narrow-band blue light across the surface of an intended target and the camera takes an image of the target with the overlayed pattern. The projector and lens of the camera are at a known angle to each other which allows for easy triangulation of the pixels of pattern images taken. The lens magnifies the area being measured and condenses pixels for finer detail scanning. The measuring area of the ATOS Q used in this cell has a working distance of 490 mm from the camera to the part surface. The sensor captures up to 2 x 12 million coordinate points per scan. The scan volume for this scanner is variable between 100mm x 70mm – 500mm x 370mm. After a projection occurs, the camera captures an image of the patterned surface, and that image is converted into a STL format with the help of reference points. When multiple scans are conducted, the respective images are stitched together. Areas of overlap are verified against one another, and new areas are added on. At the end of the scanning process all the images are “polygonised”, which means they are all combined into a single STL.

Scanner Configuration

As displayed in Figure 1, the scanner is located in a fixed position above the linear track and part positioner. Once the part positioner moves the part into view of the blue light scanner, the scanner is instructed to take an initial scan. The scanner determines its subject’s position via reference points on the pallet and displays its respective field of view in the accompanying GOM Inspect software. With the scanner aimed directly downwards, legible scans of the top of the part are easily attained as shown in Figure 1. This is due to the ability of the blue light to evenly distribute and scan directly across the surface with minimal shadows, feature obstructions and surface slopes.

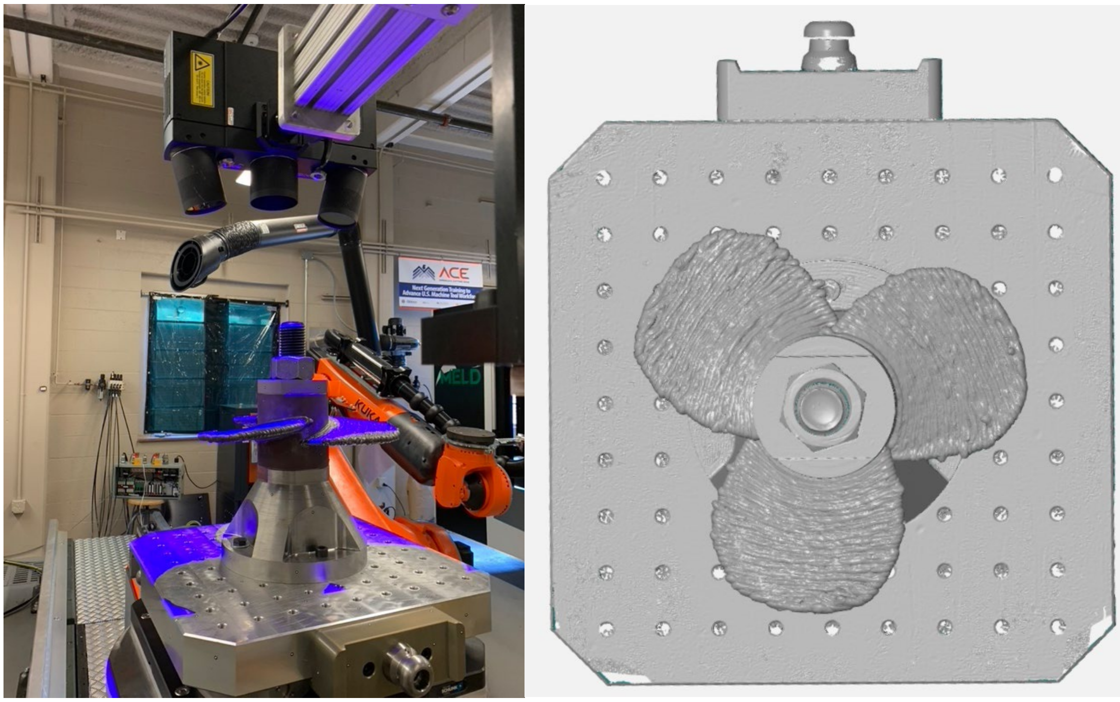

Figure 1: Static Configuration of Scanner with Respective Scan

The underside of the blades, however, presents challenges as the part positioner must be tilted and rotated to appropriately be in view of the scanner (Figure 3). This causes light illumination to then strike the part at a shallow angle instead of directly perpendicular to the surface. The blue light striking at an angle leads to data dropout caused by shadows created by irregularities in the geometry, the base plate, or the light missing the part altogether. The underside of the blade requires a near 90-degree tilt of the part positioner. However, when the part positioner is tilted beyond an 85 degrees the base plate begins to overshadow the part from view of the scanner. The scan of the underside of the three-blade geometry is displayed in Figure 3. The areas of blue indicated data dropout, or areas where the certainty of the data collected cannot be verified. The resulting part geometry required 535 scans, which causes the scanning process to be longer than printing or machining. Printing the three-blade part requires approximately 3-4hrs, while machining requires 2hrs. Manual part scanning, moving the part positioner incrementally via the control pad, requires 6hrs, nearly double the print time, and three times the machine time. Each scan requires the part to be moved into desired position, the scanner must be actuated, then the blue light scans across the surface and an image is created. Even once this process is automated, each scan takes roughly 30 seconds to complete. This also does not include the time required to polygonise the scans together into one CAD model. Note that the time necessary for polygonising increases with the number of scans administered.

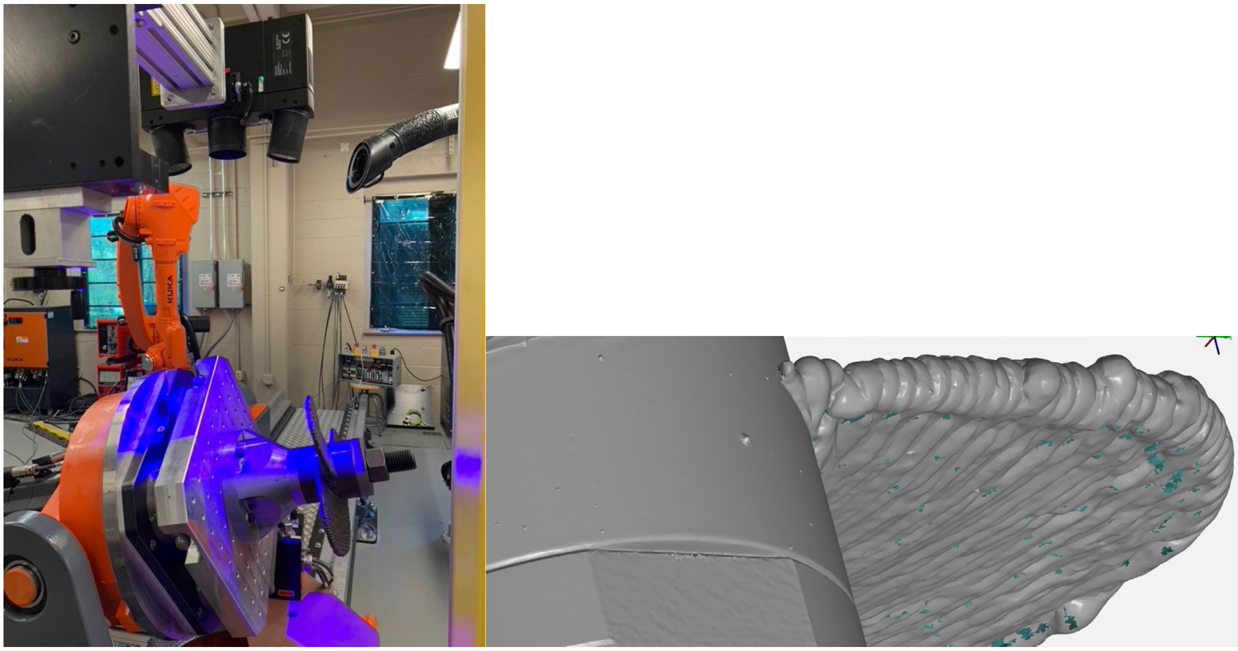

Figure 2: Scanning of Underside Of Three Blade Geometry.

To combat this, various configurations of the scanner were examined for ideal imaging. These studies determined that when the camera was tilted at a -25-degree angle, the underside scan of the part dramatically improved without significantly complicating or reducing the quality of the top surface scan of the blades. This configuration presented similar data drop out, but dramatically reduced scan time. Figure 4 displays the result of less than 200 scans in this configuration. A culmination of 200 scans requires a little over an hour and a half to complete at the rate of 30 seconds per scan. This reduces the amount of time required for adequate scanning by over a factor of 2.

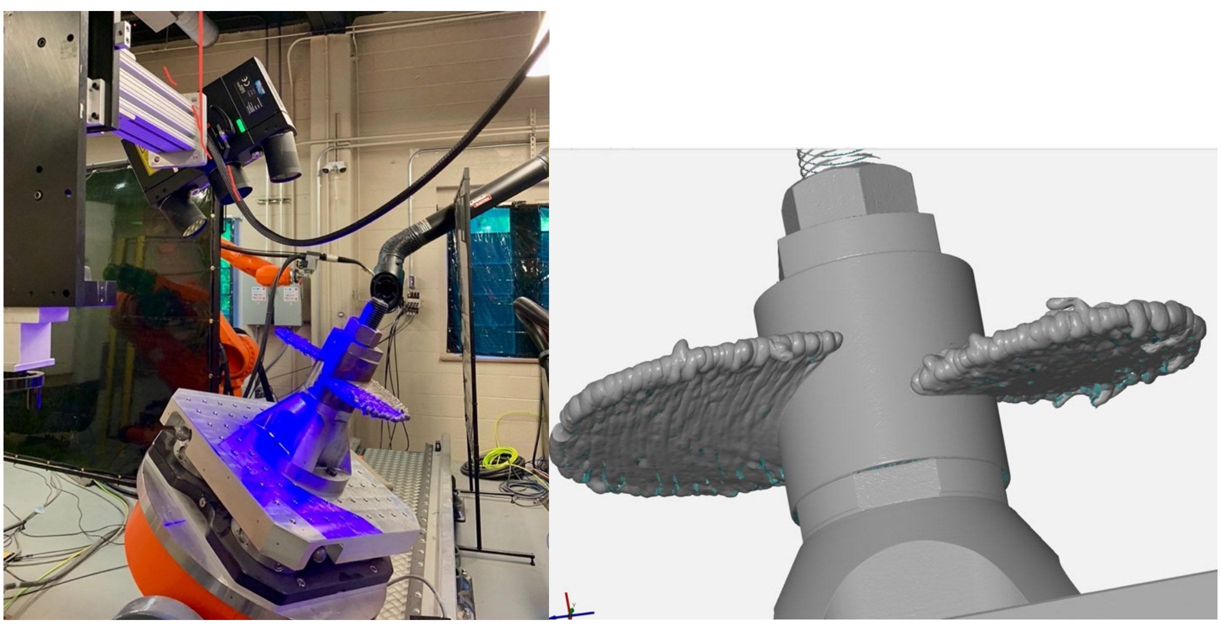

Figure 3: Underside Of Geometry Scanned From -25 Degree Position Of Scanner.

Data Analysis

After printing, prior to machining the geometry presents different challenges than a machined part. Prior to machining, the layers of printing on the part cause for some anterior areas to be obstructed, leading to data dropout. Fortunately, these layers are still able to be analyzed via the GOM software to determine layer height, thickness, etc. as seen in Figure 4. This data is useful to determining errors made during the printing process such as overheating, excessive cooling, or misalignment. Unit vectors are placed along a single "slice" of the scan to determine the layer height and thickness.

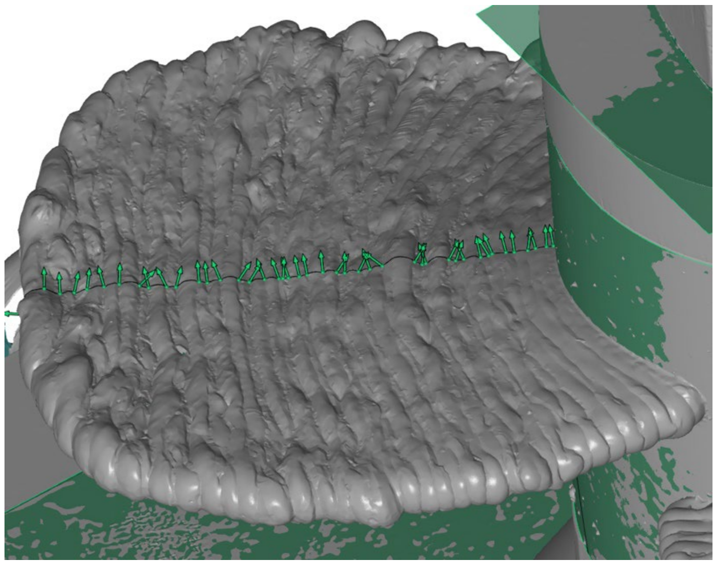

Figure 4: Layer Height Study

Parts post machining face their own challenges when scanning. Machined parts are difficult to scan due to the reflective nature of the material. When the light reflects from the part, the scanner is unable to analyze it accurately. The use of scanning spray greatly improves scan quality but is an improbable option for our cell given the objective of automation. A study was conducted to aid in understanding of the accuracy of the scanner with varying surface finishes and configurations. Spheres of identical diameter (1 inch) but different finishes were scanned from the same configurations to analyze the effects of surface finish on scan quality. These sphere scans were then compared to a CAD model of a standard 1-inch diameter sphere (Figure 5). This study also provides a visual representation of the field of view of a specified configuration of the scanner in relation to a geometry.

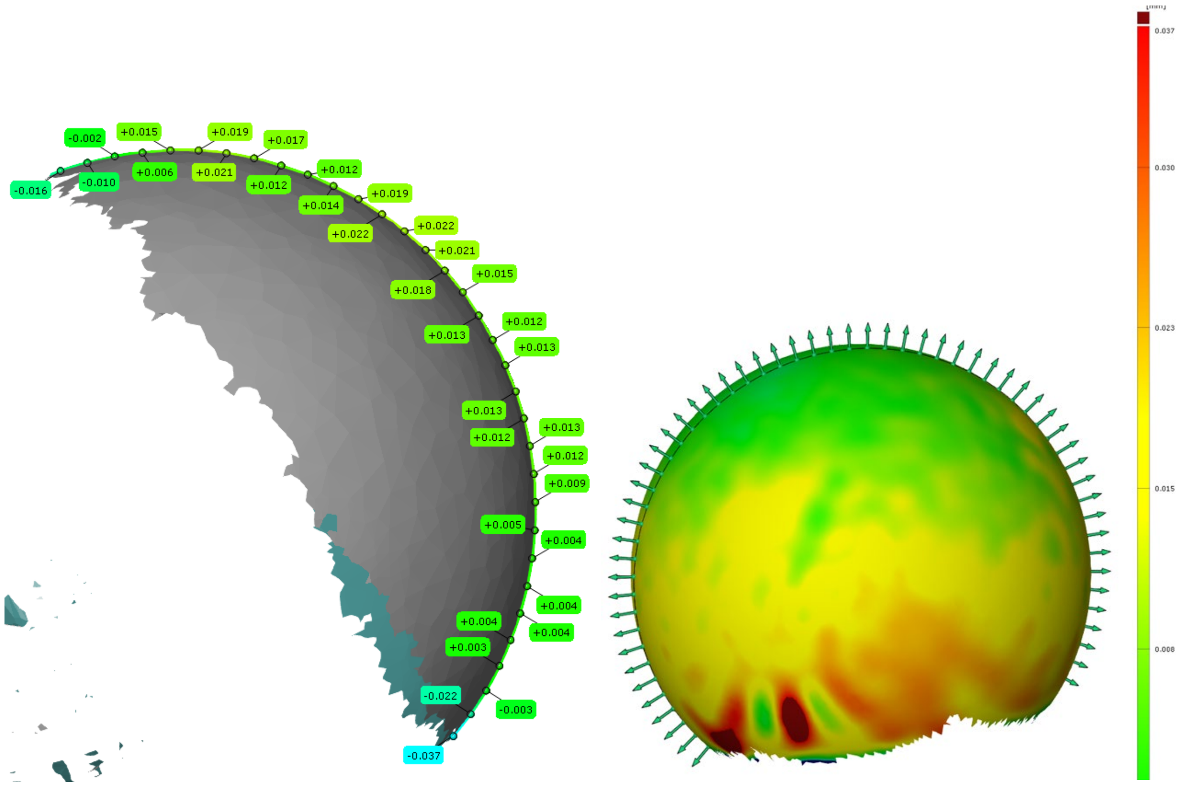

Figure 5: Matte Finish Sphere Study Deviation Of Scan To Expected CAD In Mm.

For each study, reference points were evenly plotted along a section of the sphere and used to analyze the deviation from the expected data and the data provided by the scan. These reference points were exported into an excel file to be analyzed independently of the GOM software. Plots were created for each experiment comparing error of the scan data to the position along the sphere. This data provides some insight as to where data dropout is most likely to occur when scanning from each configuration.

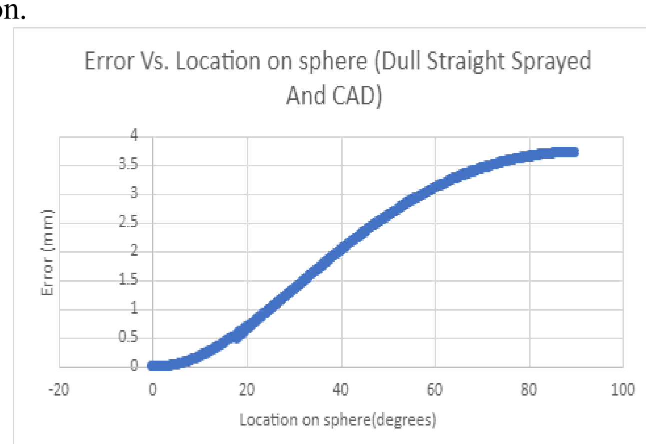

Figure 6: Error Vs. Location On Matte Finish Sphere

The plot above (Figure 6) is an example of many derived from the data collected from each of the spheres. Notice the steeper the angle gets on the sphere the more error it experiences. This is to be expected as the sphere isn't reflecting as much light back into the scanner, much of it is missing the sphere entirely.

Conclusions/Summary

Integrating metrology into the hybrid manufacturing cell via fringe projection scanning greatly improves efficiency and quality of the product created. With an informed process via the 3D scanner the needs of a product are quickly identified and met. The sphere study conducted concluded the exact field of view of the scanner in relation to a part and aids in determining an ideal scanning information that can be used for optimal path planning of the part positioner.

Future Work

A current area of research being explored is the potential to use a Kuka KR250 robot to articulate the GOM ATOS Q scanner as a tool and path plan the most ideal scanning configurations for a specified geometry. This would allow for ease of access to complex geometries that would be nearly impossible to scan from a static configuration. Figure 7 below displays a simulation created via Octopuz software of the scanner mounted at a 90-degree angle relative to the gripper axis(?). Mounting at 90 degrees allows for more intricate scan positions without nearing joint limits of the robot. The shaded red box displays the field of view of the scanner. Notice the geometry on the part positioner is more complex than the previous three-blade geometry, but much of the geometry remains within the field of view of the scanner. The robot would also be able to move the scanner into an angle/position the combination part positioner and static configuration could not. Coupling the part positioner to the KR250 for scanner the same way it is conducted for welding increases the available degrees of freedom from three to eight degrees of freedom, which vastly expands our potential area of operation. In our hybrid cell, once the part finished machining it would be translated forward for scanning just as before. The KR250 would scan the part via the scanner, then place the scanner into a storage mount to the side. The KR250 then picks the pallet up as normal and transports it for machining. Post machining, the pallet is returned to the scanning position via the KR250. The KR250 then releases the pallet, picks the scanner back up from the storage mount, and administers another round of scanning.

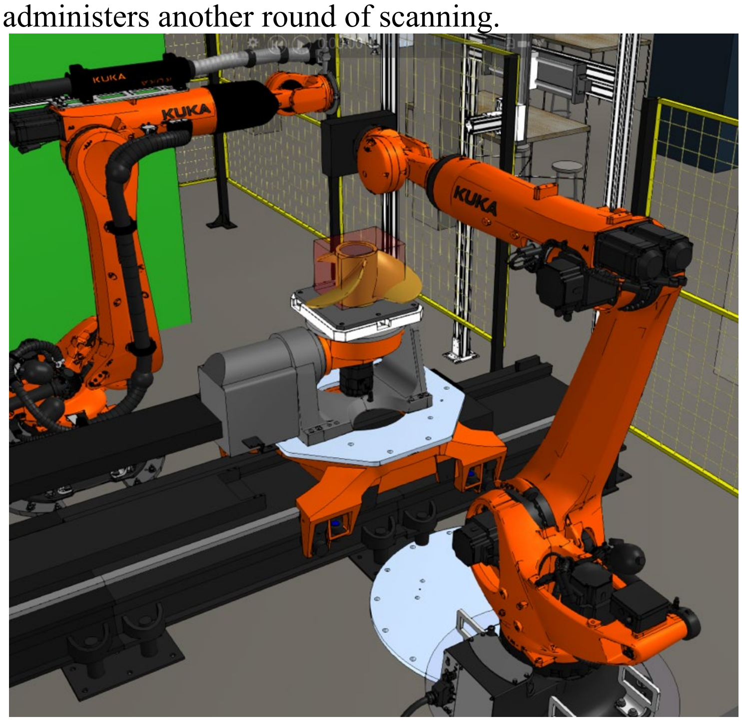

Figure 7: KUKA KR250 with GOM Mounted ATOS Q Scanner

Keywords
Hybrid manufacturing, wire-arc additive manufacturing, machining, fringe projection scanning

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