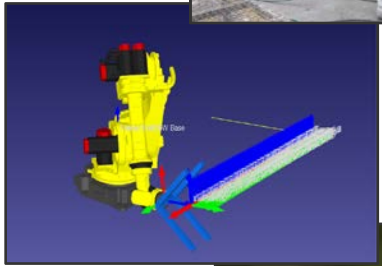

Wind Turbine Blade Finishing Automation:

Robotic Toolpath Generation

Casey Nichols, Research Engineer, NREL

IACMI Wind Energy Working Group, May 2021

Agenda

- Introduction
- Background – Wind Turbine Blade Finishing
- Industrial Robots in Blade Finishing
- Introduction to three-dimensional (3D) Imaging
- Point Cloud Generation and Processing
- Robotic Toolpath Generation
- System Integration
- Conclusion
- Future Work

GE-LM 107-m blade
Source: LM Wind

NREL's Composites Manufacturing Education and Technology Facility (CoMET)


By Dennis Schroeder / NREL 41872


By Dennis Schroeder / NREL 54061

Transforming ENERGY

NREL advances the science and engineering of energy efficiency, sustainable transportation, and renewable power technologies and provides the knowledge to integrate and optimize energy systems.
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Project Partners

- GE Renewables and GE Research Center
- LM Wind
- The Institute for Advanced Composites Manufacturing Innovation (IACMI)
- U.S. Department of Energy Advanced Manufacturing Office
- Colorado Office of Economic Development and International Trade

GE Renewable Energy

LM WIND POWER
a GE Renewable Energy business

The Institute for iacmi Advanced Composites Manufacturing Innovation
THE COMPOSITES INSTITUTE

U.S. DEPARTMENT OF ENERGY | Office of ENERGY EFFICIENCY & RENEWABLE ENERGY
ADVANCED MANUFACTURING OFFICE

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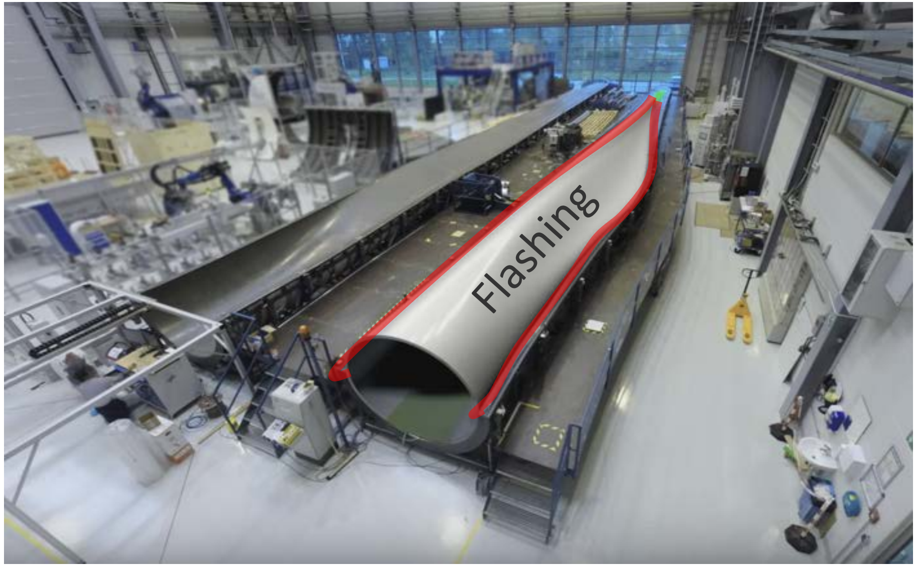
Wind Turbine Blade Manufacturing Process

1. Each component is infused in separate molds
2. The shear web is bonded to one of the skins in the clamshell mold
3. The clamshell mold is closed with the shear web inside, and then all components are bonded together.



DNV GL Clamshell Molds
Source: North American Wind Power

Finishing Wind Turbine Blades

Flashing trimming
Source: LM Wind

Grinding
Source: LM Wind

Achieving Optimal Leading and Trailing Edges

After flashing trimming, the leading and trailing edges have a small ridge that must be ground off to achieve the desired airfoil profile.

Preoverlamination blade root
Source: LM Wind

Blade Finishing From an Environmental Health and Safety Point of View

Blade finishing includes the following risks:

- Dust explosion hazard
- Respiratory hazard
- Excessive noise injury
- Musculoskeletal injury
- Work from heights
- Fatigue

Source: Klingspor Windpower

Source: LM Wind

Robotic processes are involved in the manufacturing of blades but there are no major successes in blade finishing

- ABB blade painting solution

ABB blade painting robots
Source: ABB

- Kuka mobile platform blade polishing

Kuka robotic polishing mobile platform
Source: Kuka

The Challenge: Remove the Uncertainty of Blade Geometry To Enable Robotic Toolpath Following

The root
Source: General Electric

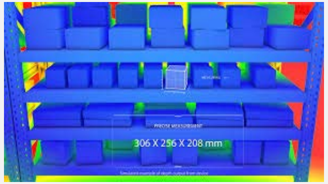
The tip
Source: Vestas

The solution: capture the blade geometry as-built and process the data to determine the robotic finishing toolpath.

3D imagining used to be a high-tech, expensive process but is now available in easy-to-use, low-cost packages







Sources: Intel, LUCID Vision Labs

Camera	Advertised Precision	Frames Per Second (fps)	Field of View	Price
Intel Realsense D415	< 2% at 2 meters (m)	90 fps	0.5–3 m	$150
Intel Realsense L515	5–14 millimeters (mm)	30 fps	0.25 m–9 m	$350
Lucid Vision Helios2	+/- 4 mm	30 fps	0.3–8.3 m	$1,500

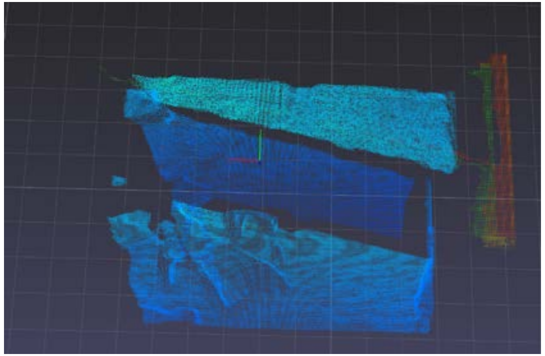
Selection Criteria
1 – Precision/Cost 2 – Field of View 3 – Availability of API

3D Imaging – Stereo Depth vs. Lidar

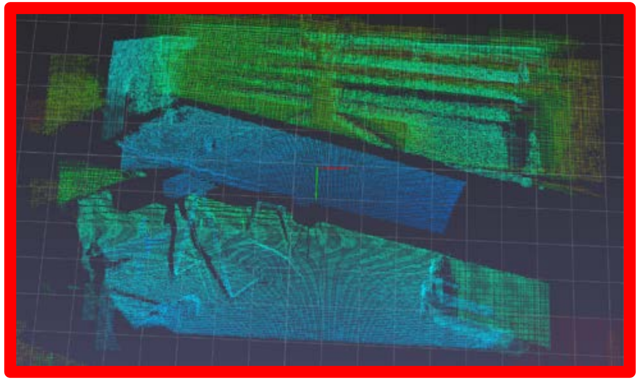
- Stereo depth perception
- Intel Realsense D415

- Lidar imaging
- Intel Realsense L515

Color image

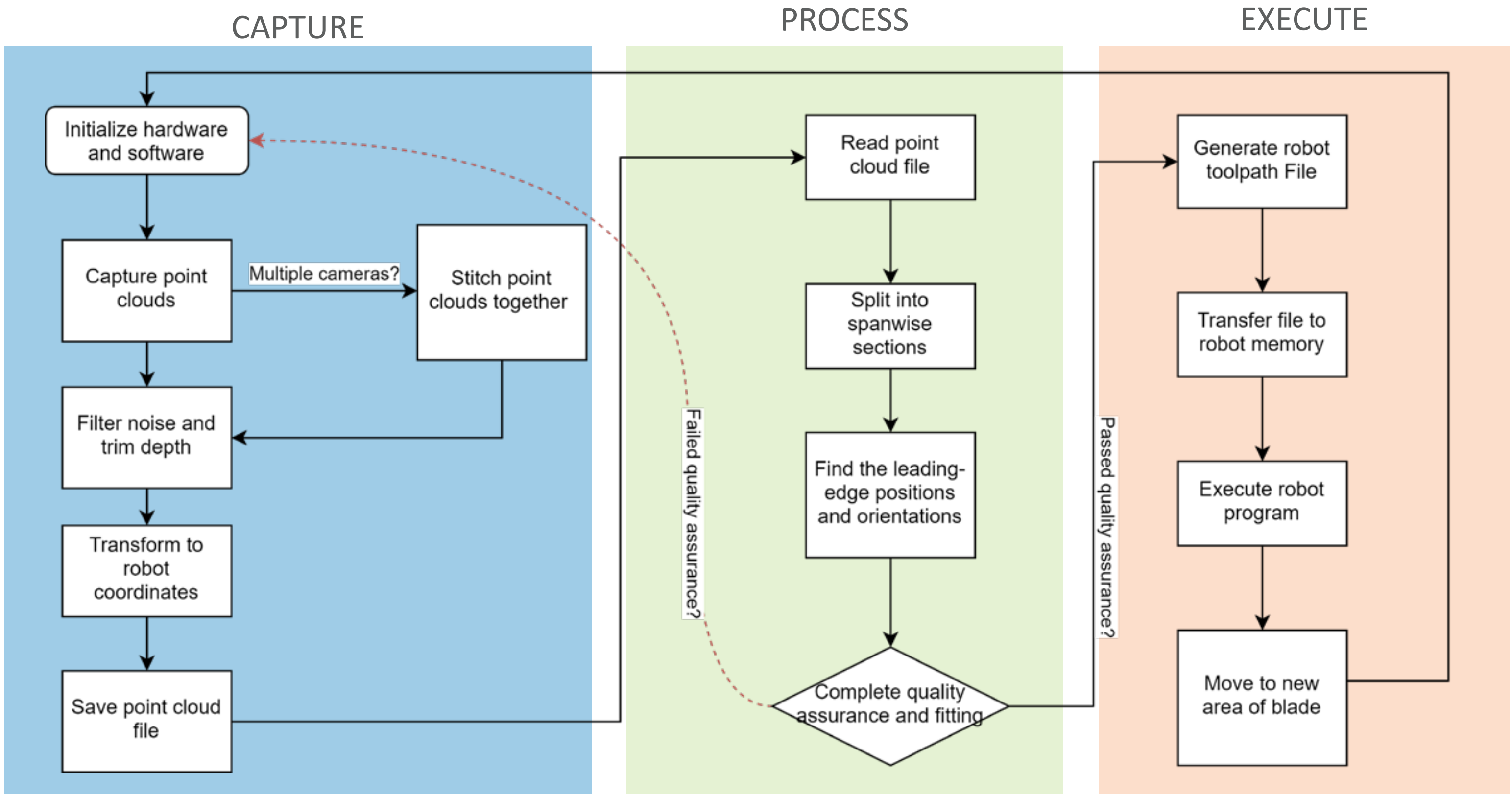


Stereo D415



Lidar L515

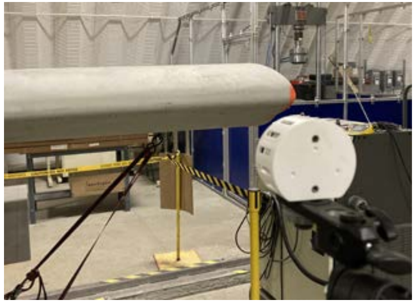
Procedure Overview



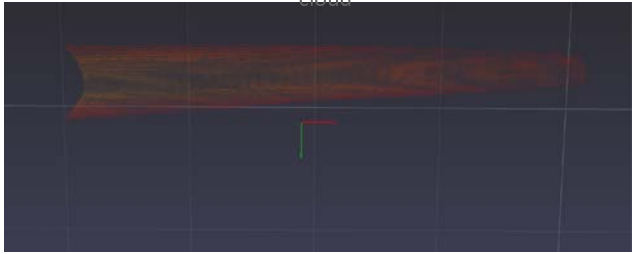
Capturing the Point Cloud With the Camera

CAPTURE

- Using the Intel Realsense API in Python, the point cloud is captured and stored in memory
- If multiple cameras are used, the point clouds must be stitched together to form one point cloud
- The point cloud is then edited to remove unneeded data
  - Limit depth from camera to remove background geometry
- The point cloud coordinates are based on the camera location so the points must be transformed into robot coordinates.

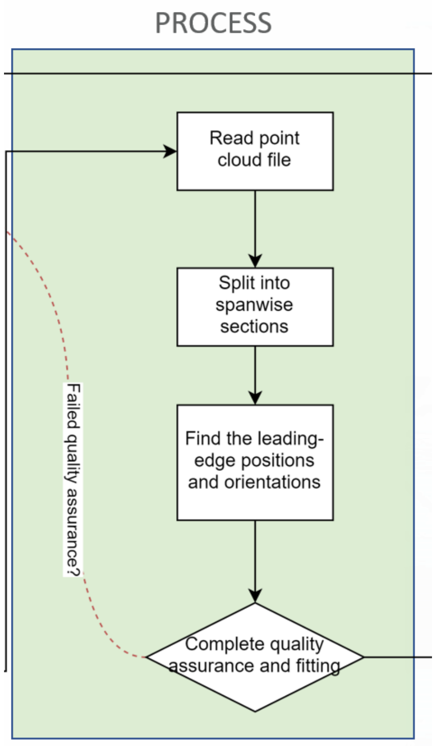


Intel L515 capturing blade section point cloud

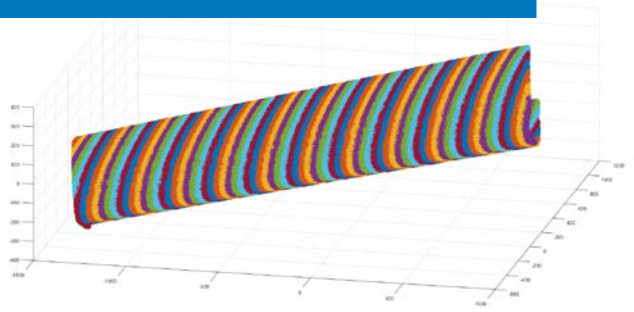


Rendering of leading-edge point cloud

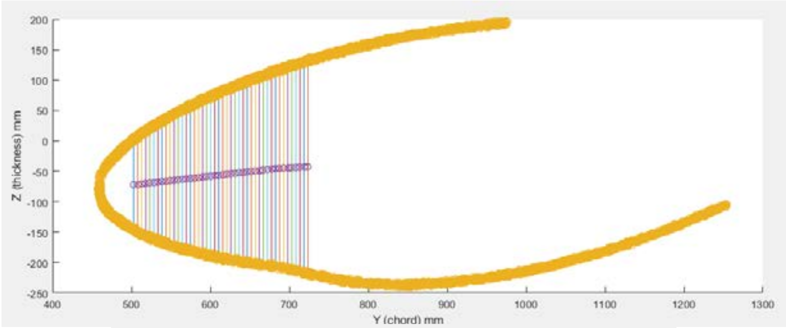
Point Cloud Processing – Part 1



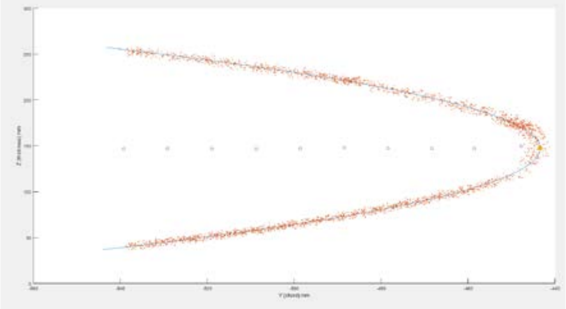
Split point cloud into spanwise sections



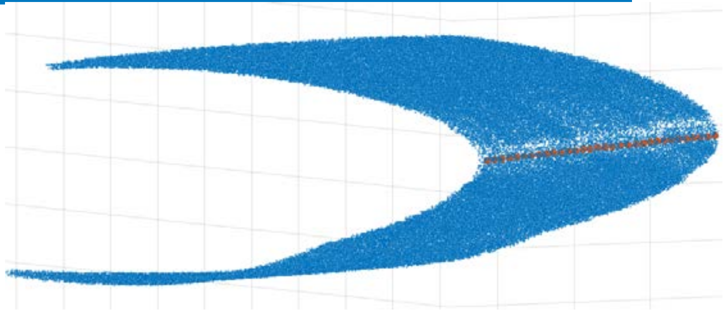
Determine twist angle of blade and rotate to achieve parabola shape



Fit rotated point cloud with second-order polynomial



Point Cloud Processing – Part 2



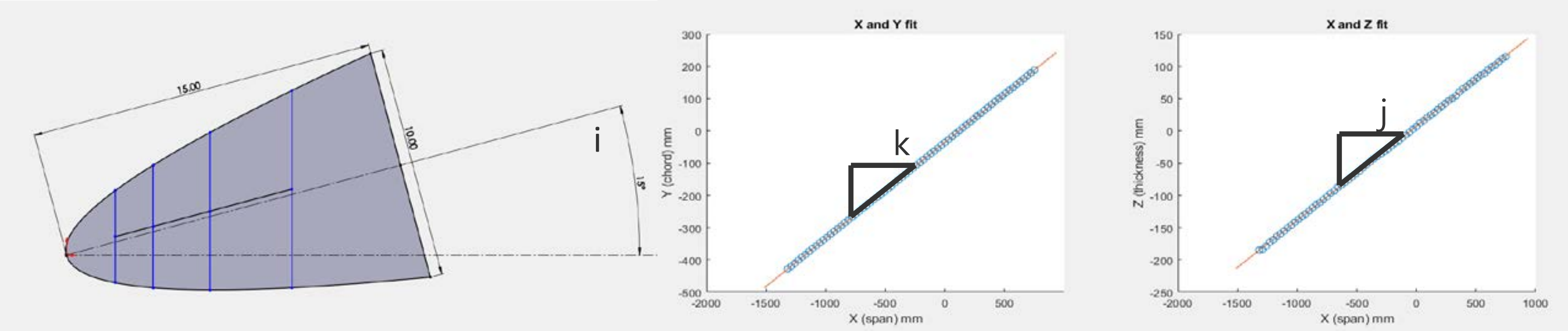
Leading-edge points are rotated back to blade coordinates

I – rotation about the span axis (x) – same as twist angle

J – rotation about the chord axis (y) – determined from X and Z fit

K – rotation about the thickness axis (z) – determined from X and Y fit

The orientation of the robot end effector is determined by the geometry of the blade



When the Toolpath Generation Process Is Complete, the Program Can Be Uploaded to the Robot and Executed

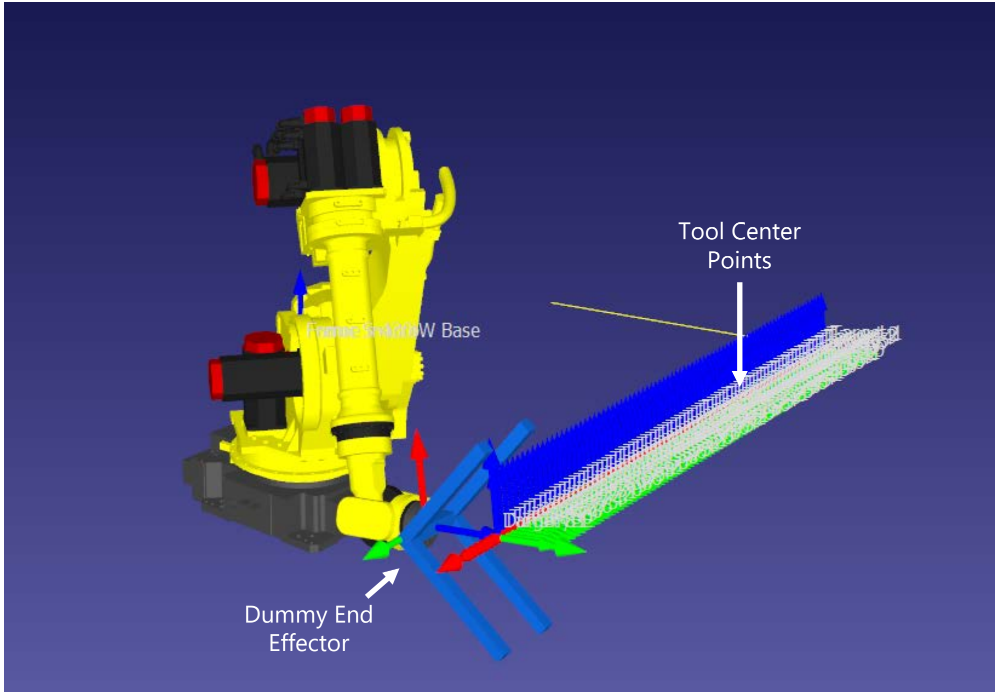
EXECUTE

- Final steps may include:
  - Including any offsets necessary for end effector design
  - Conducting toolpath quality assurance (by technician)
- This step is robot-dependent, meaning:
  - There are several ways to turn a list of tool center points into an executable robot file
  - One way to simulate the toolpath is with an offline robotics simulator like RoboDK.

Robot Simulation of Toolpath in RoboDK

EXECUTE

Writing toolpath to RoboDK simulation software with MATLAB

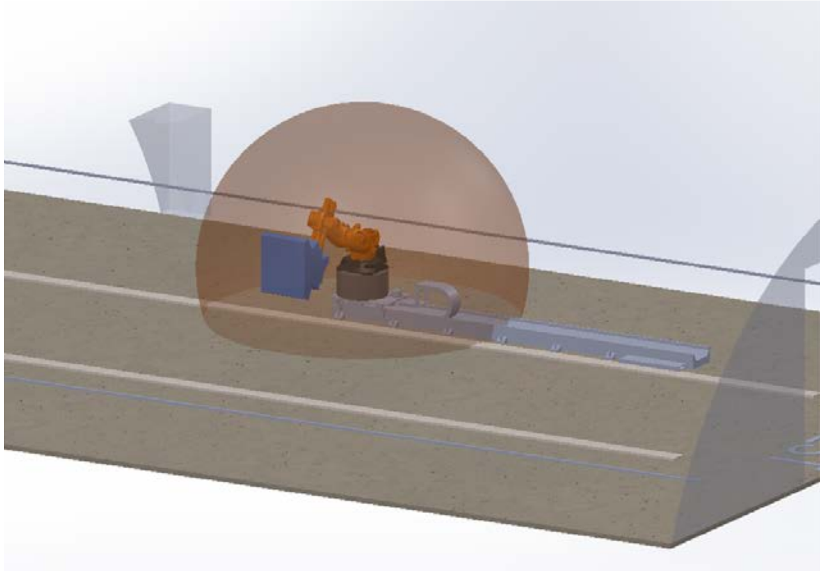


NREL-GE-LM Wind: Grinding End Effector Research

- The toolpath just defines the 6-degree-of-freedom position of the leading edge, which requires the robot end effector to adapt to the varying profile of the airfoil.
- Novel end effectors are under development with project partners to reduce cycle time and maximize efficiency.

NREL Robotic Research Platform

- The Kuka KR300 R2500 with a 6-m linear rail is in procurement and due for commissioning in September 2021.
- This system will further improve NREL's capabilities to design and test automated blade-finishing solutions.



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By Dennis Schroeder, NREL 41790

Thank You!

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Contact Info:
Casey.Nichols@nrel.gov

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