Wind Turbine Defect Detection using Terahertz Imaging

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Wind Turbine Blades

• Wind turbine blades are made out of layers of fiberglass fabric.

• During the manufacturing of wind turbine blades, defects sometimes form below the surface which can’t be seen.

• These defects eventually cause cracks, leading to costly repairs or catastrophic failures.
Defect Detection

- Defects include wave defects, out-of-plane wrinkling, delaminations, voids, and resin-rich pockets.
- The goal is to detect these defects before the blade leaves the factory.
- The defects are below the surface and can’t be seen by eye.
Terahertz Imaging

- Terahertz imaging is able to see inside of objects.
- Unlike x-rays, terahertz rays are not harmful.
- Terahertz imaging can potentially detect wind turbine defects.
What are Terahertz Waves?

Electromagnetic waves with a frequency between radio waves and infrared.
Coherent Terahertz ISAR Imaging

- ISAR images are formed by acquiring coherent continuous-wave scattering measurements at several frequencies and object rotations
- The data is then 2D Fourier transformed to yield spatial images
- ISAR images are acquired in four polarization channels: HH, HV, VH, and VV
Coherent Terahertz ISAR Imaging
Coherent Terahertz ISAR Imaging
Several test samples with known defects were acquired from Sandia National Labs and TPI Composites, and imaged at 0.1 and 0.16 THz at UMass Lowell
Image Compositing

We found that the individual ISAR images of the wind turbine samples did not capture the defects well. Therefore, my team developed an image compositing algorithm that combines many ISAR images taken at different angles.
Results

Even with image compositing, defects only showed up for some of the samples.
Traditionally, the four polarizations make up a scattering matrix:

\[
\begin{bmatrix}
E_{H}^{\text{scat}} \\
E_{V}^{\text{scat}}
\end{bmatrix} =
\begin{bmatrix}
S_{HH} & S_{HV} \\
S_{VH} & S_{VV}
\end{bmatrix}
\begin{bmatrix}
E_{H}^{\text{inc}} \\
E_{V}^{\text{inc}}
\end{bmatrix}
\]

My team developed an optimized Euler transform that diagonalizes the scattering matrix and converts the data to more meaningful parameters:

\[
S_D = U^{T}S U
\]

\[
U = \begin{bmatrix}
\cos(\psi) \cos(\tau) - i\sin(\psi) \sin(\tau) & -\sin(\psi) \cos(\tau) + i\cos(\psi) \sin(\tau) \\
\sin(\psi) \cos(\tau) + i\cos(\psi) \sin(\tau) & \cos(\psi) \cos(\tau) + i\sin(\psi) \sin(\tau)
\end{bmatrix}
\]

\[
S_D = \begin{bmatrix}
me^{i2\nu} & 0 \\
0 & m \tan^2(\gamma) e^{-i2\nu}
\end{bmatrix}
\]
Optimized Euler Transform

HH Image

Euler $m$ Image
Optimized Euler Transform

\[ \gamma, \psi, \nu, \tau \]
Quantitative Evaluation

- Algorithm developed to calculate numeric score signifying how well an imaging approach found defects.
- User draws box where each defect is known to be.
- Score is calculated from contrast between defect region and surrounding pixels.
Results

![Graph showing the defect imaging score over the number of images.](image)

- HH
- HV
- VH
- VV

defect imaging score vs. number of images
Conclusions

- Terahertz imaging can successfully detect subsurface defects in wind turbine blades.
- The image compositing algorithm improves defect detection.
- The optimized Euler transform improves defect detection when using the $m$ parameter.
- Despite these improvements, the defects in many of the samples were still undetected.
Future Work

● Improve the image compositing and Euler transform so that all defects can be found.

● Simplify the imaging equipment so that it can be used in the factory on full wind turbine blades.
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