

# Team 6: Robotic Laser Ultrasound for Inspection of Complex Structures

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**DESIRED STUDENT SKILLSETS:** Acoustics, nondestructive evaluation, robotics (kinematics, path planning), AI/ML (deep learning, computer vision)

## ABSTRACT

This project will develop a method for generating fully three-dimensional wavefields using laser ultrasound, robotic manipulation, and neural rendering techniques. Acoustic Steady-State Excitation Spatial Spectroscopy (ASSESS) is a non-destructive evaluation (NDE) method that excites structures at controlled frequencies and measures their spatial vibration response using scanning laser Doppler vibrometry. Conventional ASSESS produces two-dimensional spatial spectroscopy maps; however, complex geometries and subsurface defects require complete 3D characterization. To address this limitation, you will integrate a six-degree-of-freedom (6-DOF) robotic manipulator (UFactory serial arm) with ASSESS measurements and leverage Neural Radiance Fields (NeRF) to reconstruct volumetric 3D wavefields from sparse scan data. NeRF is a deep learning framework that models a scene as a continuous function mapping spatial coordinates and viewing directions to radiance and density, enabling high-fidelity reconstruction from limited 2D observations. The resulting 3D spectral fingerprints will enhance defect detection and characterization in complex structural components, improving non-destructive testing capabilities for identifying cracks, corrosion, and material property variations.



Figure 1: UFACTORY X-arm 6

## PROJECT OUTLINE

**Goal** – The goal of this project is to design, build, test, and validate a robotic ASSESS framework capable of generating three-dimensional wavefield reconstructions for enhanced structural health monitoring and defect detection. This framework will integrate a 6-DOF serial manipulator for automated multi-perspective scanning, combine laser Doppler vibrometry measurements with controlled acoustic excitation, and employ Neural Radiance Field (NeRF) models to synthesize complete 3D wavefield volumes from spatially distributed measurements. The proposed approach will be validated using test specimens with known defects in a laboratory environment.

**Motivation** – Traditional ASSESS techniques have proven highly effective for defect detection in planar or simple geometries by generating 2D spatial spectroscopy maps that serve as structural fingerprints. However, many engineering components feature complex 3D geometries, internal structures, or defects that cannot be adequately characterized from a single viewing angle. Manual repositioning of laser vibrometers is time-consuming, imprecise, and limits measurement density. By integrating robotic manipulation, we can achieve repeatable, high-density scanning of complex surfaces from multiple perspectives. Furthermore, recent advances in neural rendering, particularly NeRF models, have demonstrated remarkable capability in reconstructing continuous 3D representations from sparse viewpoint data. This project seeks to harness these technologies to transform ASSESS from a 2D surface technique into a comprehensive 3D volumetric characterization tool, enabling detection and localization of defects that would be invisible or ambiguous in traditional 2D scans.

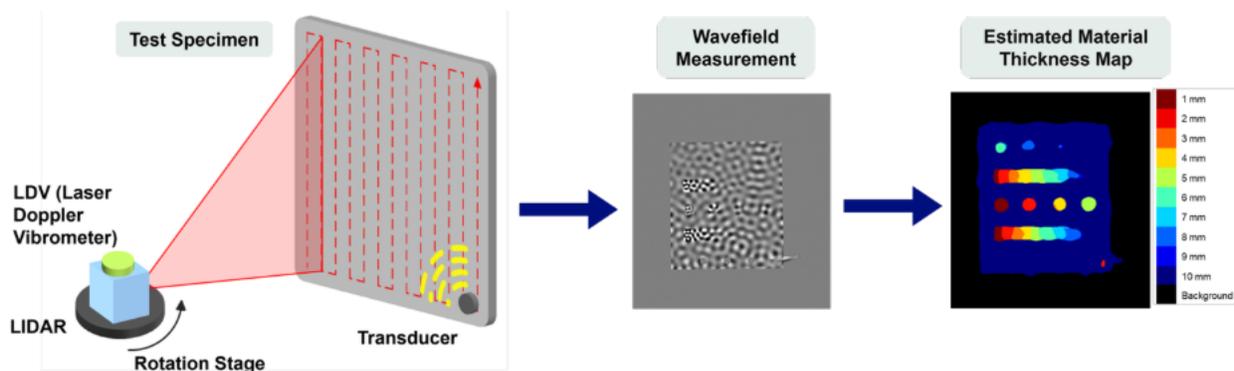


Figure 2: Current ASSESS approach.

**Procedure** – The project will follow a structured approach beginning with system integration and calibration of the U-Factory 6-DOF manipulator with the laser Doppler vibrometer and acoustic excitation system. You will develop path-planning algorithms to systematically scan test specimens from multiple orientations while maintaining optimal sensor positioning. A NeRF-based reconstruction pipeline will be developed to process spatially distributed vibration measurements and synthesize complete 3D wavefield volumes. The framework will be validated

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using specimens with controlled defects (cracks, voids, material variations) by comparing reconstructed 3D wavefields against expected patterns. Key steps include:

1. Integrated and calibrate the robotic manipulator with ASSESS instrumentation
2. Develop automated scanning trajectories for multi-perspective data acquisition
3. Collect synchronized vibrometry data across multiple excitation frequencies
4. Train and adapt NeRF models for vibration wavefield reconstruction
5. Validate 3D wavefield accuracy and defect detection capability on test specimens
6. Analyze sensitivity to scanning density and measurement noise

### WEEK-BY-WEEK PLAN

Week	Objectives
1	Complete literature review on ASSESS, NeRF, and robotic NDE. Complete hazard analysis, orientation, and training activities.
2	Set up U-Factory manipulator. Configure laser Doppler vibrometer.
3	Develop robot-sensor coordination. Perform hand-eye calibration. Implement basic scanning trajectory. Write literature review portion of paper.
4	Develop automated scanning protocol. Test multi-perspective data acquisition; Complete baseline 2D ASSESS measurements on simple specimens.
5	Introduce NeRF architectures. Complete initial data formatting and preprocessing for neural rendering pipeline.
6	Collect multi-view ASSESS datasets at various excitation frequencies. Synchronize data and validate quality. Write methods portion of paper.
7	Train NeRF model for wavefield reconstruction. Optimize hyperparameters.
8	Refine and validate model. Visualize 3D wavefield. Assess accuracy.
9	Defect defects on test specimens. Compare 2D and 3D ASSESS performance; Study sensitivity. Write analysis portion of paper.
10	Finish technical paper. Complete final presentation.

## REAL WORLD DESIGN ISSUES AS A PROJECT CONSIDERATION

**Measurement Registration:** Accurate spatial registration between robot position, laser measurement point, and part coordinate frame is critical for 3D reconstruction quality. Calibration errors will propagate through the reconstruction.

**Scanning Efficiency vs. Resolution Trade-off:** Dense spatial sampling improves reconstruction fidelity but increases acquisition time. Optimal scanning strategies must balance coverage with practical time constraints.

**Surface Accessibility and Occlusion:** Complex geometries may have surfaces inaccessible to line-of-sight laser measurements. Path planning must identify and maximize coverage of feasible measurement locations.

**Model Generalization:** NeRF models trained on specific geometries and excitation frequencies may require adaptation strategies to generalize across different parts and damage types.

## BACKGROUND LITERATURE

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- [2] Flynn, E. B., Chong, S. Y., Jarmer, G. J., & Lee, J.-R. (2013). *Structural imaging through local wavenumber estimation of guided waves*. *NDT & E International*, 59, 1–10.
- [3] Mildenhall, B., Srinivasan, P. P., Tancik, M., Barron, J. T., Ramamoorthi, R., & Ng, R. (2020). NeRF: Representing scenes as neural radiance fields for view synthesis. In *European conference on computer vision* (pp. 405-421). Springer, Cham.
- [4] Cao, C., Wu, X., Yang, S., Xu, Y., & Zhou, H. (2022). Neural radiance fields for robotic applications: A survey. *arXiv preprint arXiv:2208.13482*.
- [5] Di Scalea, F. L., Matt, H., Bartoli, I., Coccia, S., Park, G., & Farrar, C. (2007). Health monitoring of UAV wing skin-to-spar joints using guided waves and macro fiber composite transducers. *Journal of Intelligent Material Systems and Structures*, 18(4), 373-388.