Structural Health Monitoring of Critical Space Components Using In-situ Ultrasound Techniques

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Abstract

Space missions are expanding rapidly, yet post-launch inspection of critical hardware, especially cryogenic lines, tanks, and complex interfaces, remains impractical. An in-situ Structural Health Monitoring (SHM) method is introduced that pairs a sparse network of bonded ultrasonic transducers with an AI signal processing pipeline to detect, localize, and classify damage during operations. Preliminary tests on a complex metallic part with simulated defects demonstrate rapid, reliable diagnosis using only eight sensors, indicating feasibility for flight-like components. The approach enables continuous condition awareness and predictability, supporting safer, more resilient space vehicles throughout operational life.

Methodology

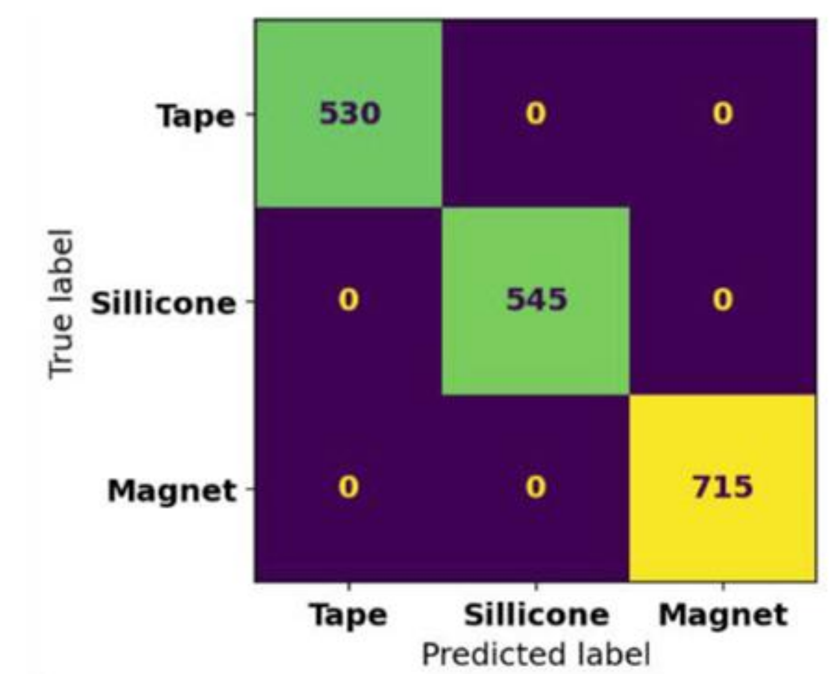
Remote SHM enables early defect detection in critical components without interrupting operations. In this study, an AI-based ultrasonic SHM approach was developed to detect and classify defects in complex structures.

A steel brake rotor hub was instrumented with eight ultrasonic sensors for automated signal acquisition using Gaussian and chirp excitations as shown in figure (a). Three defect types were simulated across multiple zones to generate a diverse training dataset.

An autoencoder-based AI model was trained on these acoustic signals to identify and localize damage as shown figure (b). The model achieved high accuracy by learning directly from complex wave patterns, demonstrating strong potential for real-time defect detection in intricate geometries.

Preliminary Results

Once the model is trained, the system achieved 100% accuracy on unseen tests across all tasks (damage detection, zone and sub-zone localization, and damage-type identification) over 2,250 samples as shown in figure (c). These results indicate precise spatial resolution, robust generalization, and dependable in-situ diagnostics suitable for post-launch aerospace components using a sparse ultrasonic sensor network with advanced AI inference.



Conclusion

The AI-driven SHM framework successfully converted ultrasonic signals into spatial damage maps . The results demonstrated accurate detection and localization of simulated defects using sensors. These findings validate the feasibility of real-time, structural diagnostics, advancing toward reliable in-situ monitoring for future space missions..

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References

[1] Palanisamy et al. Accurate and rapid acoustic damage characterization in complex structures using sparse sensor networks and deep learning models. NDT & E International.
[2] Palanisamy et al. Multi-level structural damage characterization using sparse acoustic sensor networks and knowledge transferred deep learning. Ultrasonics.
[3] The Spacecraft SHM Experiment, Part 1: Development for Space Flight
[4] Piezoelectric Wafer Active Sensor Structural Health Monitoring of Space Structures