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Inspecting Damaged Turbine Blades with Data Fusion of Coordinate Measuring Machines and 3D scanners

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Abstract

Turbine blades are critical components of turbine engines. Their complex, highly curved, free-form shapes are optimized to maximize aerodynamic efficiency. To withstand the high-pressure and high-temperature environments in which they operate, the blades are often manufactured using specialized materials such as nickel-based superalloys. Consequently, these blades are costly components of turbine engines, making their repair a more viable option than replacement in the event of damage. Effective planning of repair procedures requires accurate and thorough inspection of the blades.

Currently, coordinate measuring machines (CMMs) equipped with contact probes are widely used in the industry to inspect turbine blades. Although these instruments offer micrometer-level accuracy, their contact-based nature renders them inefficient for acquiring the high-density measurements needed to characterize the free-form shapes and surface damage (e.g., scratches, voids, or dents) of in-service turbine blades. To achieve high-density measurements, optical instruments such as 3D scanners are preferred. However, their adoption is limited by their accuracy, which varies depending on factors such as the blade's material, surface finish, and environmental conditions during scanning. Inspecting damaged turbine blades thus remains a significant challenge in the field of inspection and quality control.

To obtain the necessary high-density and high-accuracy measurements for inspecting damaged turbine blades, we propose a data fusion approach that combines CMM point clouds with 3D scan meshes of the blade. The CMM data offers low-density, high-accuracy measurements of the blade's global geometry, while the structured-light 3D scanner provides high-density, low-accuracy measurements of the whole surface including any damage. By fusing these two datasets, we aim to obtain measurements that are both high-density and high-accuracy. The proposed algorithm is a modified version of the Non-Rigid Iterative Closest Point (NR-ICP) algorithm, which corrects the measurement errors in the 3D scan by iteratively registering it non-rigidly to the reference CMM point cloud. Unlike other popular 3D metrology data fusion algorithms, NR-ICP effectively preserves surface details, not present in the CMM data.

The methodology was validated through an experimental study involving a metallic turbine blade with a dent. The damaged blade was inspected using both a CMM and a 3D scanner, and the resulting data were fused using the NR-ICP algorithm. The measurement errors in the 3D scanner data were reduced by up to 90%, while the geometry of the dent in the 3D scan mesh was preserved.