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Metrology-, Manufacturing-, and Reverse Design-Guided Repair Engineering

Repair engineering aims to monitor, diagnose, prognose, and correct system faults and malfunctions to maintain machinery and equipment as sustainable and productive as possible by applying metrology, reverse engineering, and remanufacturing concepts. Part defects include global or local deformation, cracks, wear, surface property changes, etc.; these changes in material properties (e.g., degradation of the microstructure and grain boundary cavitation at the defect zones) lead to changes in static or dynamic characteristics affecting the lifespan and performance of the overall structure or assembly. Repair engineering must be thoroughly investigated to identify those defects and determine proper repair planning to maximize the post-repair part life cycle. Therefore, repair engineering requires authoritative, objective, reliable information, including three-dimensional (3D) computer-aided design data, material design for functions, surface properties or dynamic models, and diagnosis and prognosis of the part.

To establish a repair engineering framework capable of corrective, preventive, and predictive maintenance of both geometry- and material-level part defects, fundamental research of metrology, manufacturing and reverse design and their integration and digital transformation must be conducted first. Proposed research will leverage (1) surface and material metrology, (2) structural optimization-based repair planning, and (3) metrology-guided closed-loop additive repair process control to establish a holistic repairing engineering platform. A novel metrology tool path planning enables precise part feature (geometry and material) extraction. This will provide the foundation for artificial intelligence (AI)-based two-stage structural optimization formulation; one for altered material layer removal and another on optimum repair material distribution for enhanced post-repair functionality followed by material removal and multi-axis additive manufacturing (AM) that creates a feedback loop with metrology and reverse design steps to predict and validate repaired part. This novel approach provides robust defect-specific repair strategies and can be easily scaled to various additively manufacturable material platforms (polymer, composite, metal).

The successful implementation of this research will reveal new knowledge in fundamental principles and processes of additive repair engineering, including non-destructive testing methods, defect feature inspection techniques, diagnosis and prognostics of dynamic systems, 3D image deconstruction and reconstruction algorithms, structural optimization-based reverse design and AI-based data analytics, adhesive bonding of materials, and corrective additive repair process control architecture. The outcomes of this project will enable part or system-level inspection, design, and fabrication processes under tight control, quality improvement, and reduced scrap rates to enhance environmental sustainability. The proposed research addresses the new perspective on automated metrology and inspection, recycling, and remanufacturing technology necessary for U.S. manufacturing industries and national science initiatives requiring a high level of safety management. It can quickly lead to improved productivity, innovation, higher-quality products, energy efficiency, and more advanced manufacturing jobs in the U.S. Also, the proposed technology enables quality control and repair of various electrical, electronic, chemical, material, and even bio-medical components and systems by adopting the corresponding measurement, design, and fabrication technology. The proposed research activities will also benefit STEM students who have expressed explicit interest in metrology, reverse engineering, design, and manufacturing, producing a future talented engineering workforce.