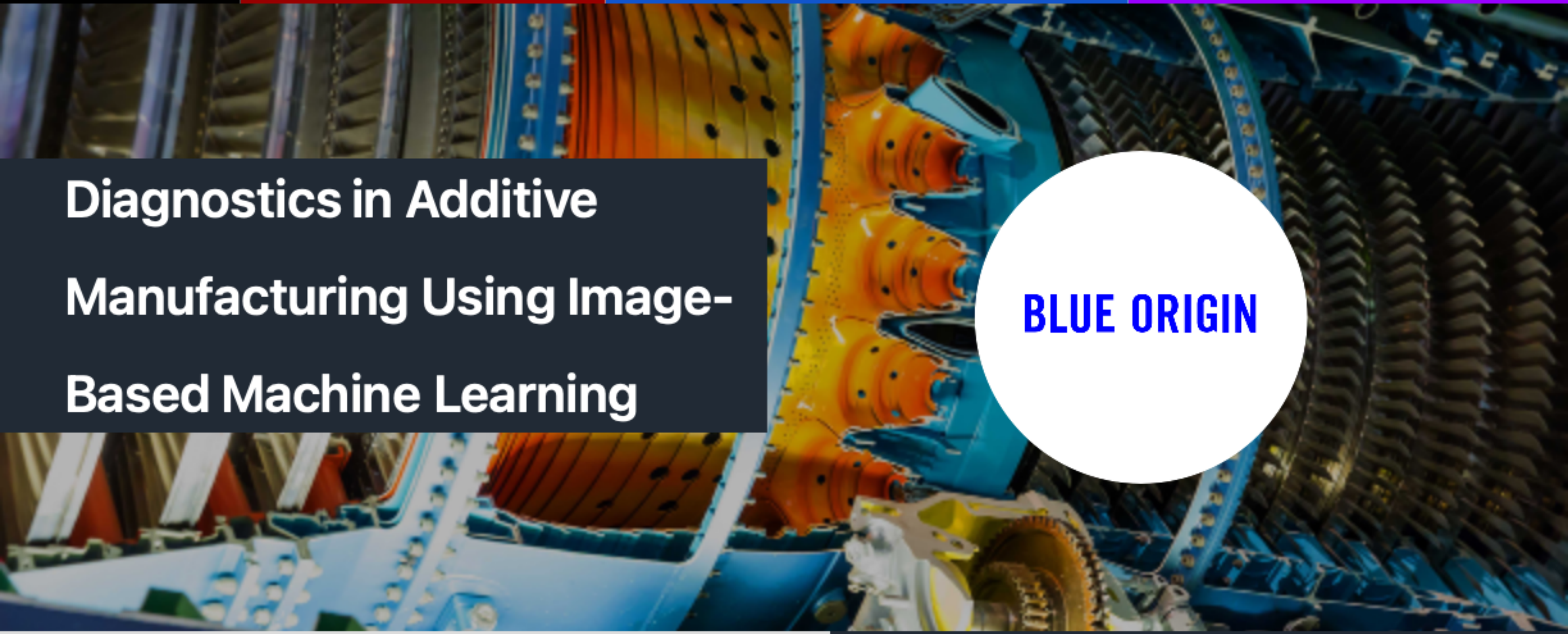
Engineering | Aerospace and defense | Defect detection / product inspection | Convolutional neural networks

Diagnostics in Additive Manufacturing Using Image-Based Machine Learning

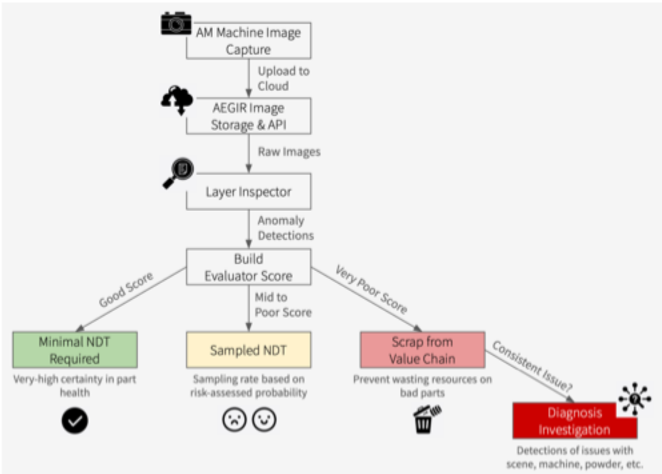


BUSINESS PROBLEM

Blue Origin faces a critical bottleneck in Additive Manufacturing: non-destructive testing (NDT). Each 3D-printed engine part undergoes volumetric NDT inspection (CT or radiography), creating unsustainable constraints. Each scan can cost $5-10k, and, due to limited resources within the US, have a lead time of 30 days, creating production delays. More critically, there are not enough aerospace-grade CT machines worldwide to support projected throughput. Without process change, meeting future customer demand will become impossible. Blue Origin needs a solution that alleviates this bottleneck without sacrificing rigorous quality standards.

APPROACH

We developed a diagnostic system that uses machine learning to analyze layer-by-layer photographs taken during 3D printing. The system identifies anomalies in individual layers using U-Net neural networks, then evaluates overall build health through an ensemble of tree-based models. This generates a process-based evaluation that enables intelligent, risk-informed allocation of NDT resources.



DATA SOURCES

Our primary data were layer-by-layer photographs of the 3D printing process. These came from AM machines that captured this "powder bed imagery." Our team also created the "Challenge Set," a dataset of 306 builds manually classified by subject matter experts. Each build contains between 1,000-20,000 layers of powder bed imagery, with classifications of "nominal" or "anomalous."

Data Types and Format

The data consisted of grayscale image sequences (640x640 pixels) captured during printing – two images per layer: one after powder delivery ("Recoat") and another after laser welding ("Exposure").

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IMPACT

Our solution turns what began as an unsustainable bottleneck into an opportunity for enhanced quality control and long-term manufacturing strategy. First, it provides visibility into the build process. Unlike end-stage NDT inspections, our system assesses real-time process signatures, revealing when and how deviations occur. This enables better root cause analysis and process improvements across manufacturing operations. Second, it alleviates the NDT bottleneck. The system can confidently bypass NDT for low-risk builds while inspecting parts that most need it. Conservative implementations reduce NDT requirements by 37-54%, and far outperform alternative approaches in anomaly detection. These calculations represent a minimum expected benefit, as Blue Origin generates a much lower percentage of anomalous builds than in our test dataset. Third, it delivers financial benefits. While exact figures are proprietary, annual cost savings reach into the millions of dollars due to reduced NDT expenditures and prevention of wasted post-processing on defective parts. These reductions also translate to accelerated production cycle times and manufacturing agility. Beyond these immediate benefits, the system creates a foundation for future manufacturing intelligence – notably, early detection of process drift, and data-driven insights that transform routine quality control into a strategic advantage.

DRIVERS

Blue Origin's (and the aerospace industry's) growing demand for rocket engines created a need to dramatically scale AM production. The global limitation of high-energy CT machines created a barrier to this scaling by constraining Blue Origin's ability to run volumetric NDT.

BARRIERS

Aerospace regulations and standards (e.g. ITAR, AS9100) limit the possible solution space. Large volumes of image data create computational challenges for iterative development. Low-information photographs hinder classification. Ambiguity exists in visual anomaly detection. The consequences of aerospace component failure mean we must take extreme caution in balancing efficiency with quality.

ENABLERS

Our "NDT Peacemakers" tiger team combined talent from Manufacturing and Engines organizations, bringing together expertise in AM machines/data and in engine design. The prior development of the AEGIR tool provided critical infrastructure for processing high-quality powder bed imagery. Blue Origin's culture of balancing innovation with necessary precaution created space for exploring creative approaches.

ACTIONS

We developed a 2-step ML system: a U-Net to identify anomalies in individual layers, and a tree-based ensemble to assess build health. We engineered statistical features to capture physical anomaly patterns. We implemented a probability sampling approach that can scale NDT allocation according to risk level. We created a rigorous testing methodology using k-fold cross-validation to ensure results maintain detection sensitivity.

INNOVATION

Our solution transforms quality control from reactive inspection to proactive process monitoring. The dual-model approach (separate for Recoat and Exposure images) captures distinct failure signatures that might be missed by a single model. Our feature engineering process extracts physical meaning from visual data, creating explainability. The logistic sampling probability approach provides flexibility in balancing detection and efficiency.

IMPROVEMENT

Our most conservative implementation achieves 100% anomaly detection while reducing NDT requirements by 37%. More balanced parameters reduce NDT by up to 54% while maintaining 80% anomaly capture – far outperforming random sampling. With NDT cycle times spanning a full month, these reductions translate to millions of dollars in cost savings and accelerated production timelines.

BEST PRACTICES

Prioritize explainability in critical applications like aerospace, and design for asymmetric risk profiles where false negatives are far more consequential than false positives. Choose designs that physically align with expert knowledge. Involve subject matter experts throughout development. Mitigate confirmation bias when reclassifying data based on model outputs.