Digital Twin Framework for Integrated Sequential Laser Beam Micromachining (LBMM) and Micro-EDM

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Abstract

Micro-hole arrays are widely used in aerospace, biomedical devices, and filtration applications. While many methods exist for producing these arrays, achieving high precision, efficiency, and low cost in a single process remains challenging. An integrated sequential method combining Laser Beam Micromachining (LBMM) for fast material removal and micro Electrical Discharge Machining (μEDM) for precise finishing offers a promising solution. However, the sequential operation of these two processes presents challenges such as collision risk, coordination difficulties, and monitoring limitations. To address these issues, this paper proposes a Digital Twin (DT) framework integrated with the Internet of Things (IoT) for real-time analysis and decision-making, which improves process coordination, collision-aware operation, and virtual validation of sequential LBMM-μEDM machining. The DT enables real-time monitoring by leveraging accurate 3D geometries of machine components to enhance the realism and precision of collision detection. The virtual 3D representation was developed using Unity3D software, while IoT connectivity for real-time data exchange was established through Firebase, resulting in an average transmission latency of 16ms. The DT eliminates the need for live camera feeds by enabling flexible, low-bandwidth, multi-angle visualization without extra hardware, while also supporting offline virtual simulations for motion coordination, realistic cutting effects, and machining time estimation with a 79.8 prediction accuracy.

Author keywords

Collision Detection; Digital Twin; Laser Beam Micromachining (LBMM); Micro Electrical Discharge Machining (μEDM); Real-time Monitoring; Sequential Hybrid Machining

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