SWAT - SYSTEMATICALLY WEAVING A DIGITAL THREAD INTO COMPOSITE PARTS

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Abstract

The manufacture of 3D woven carbon fibre preforms for aerospace and high-performance applications presents significant challenges in process variability, traceability, and certification. Despite advances in textile composite architectures, structured digital integration within weaving platforms remains limited, restricting the ability to link process parameters to preform quality and downstream mechanical performance. This work presents SWaT (Systematically Weaving a Digital Thread), a framework for embedding a structured digital architecture into a 3D Jacquard weaving line to enable real-time process intelligence and lifecycle connectivity. A 3D Jacquard weaving platform was instrumented and digitally integrated through a unified acquisition framework capable of handling high-density, high-frequency machine and process data. Machine outputs and condition data were synchronised and contextualised within a scalable data pipeline designed to ensure temporal alignment, traceability, and schema standardisation. A tiered data architecture (raw → structured → contextualised) was implemented to support robust storage, interrogation, and long-term lifecycle accessibility. Real-time visualisation interfaces were developed to enhance process transparency and enable rapid identification of anomalous machine behaviour during manufacture. Advanced signal processing and feature extraction methodologies were applied to clean, filter, and normalise process data streams, enabling statistical correlation between machine state variables and resulting preform characteristics. Predictive modelling strategies were subsequently deployed to support process optimisation, condition monitoring, and early-stage defect identification. The resulting digital thread framework strengthens understanding of process–structure relationships in 3D woven composites, supports evidence-based process qualification, and establishes the foundation for digital passports and future digital twin implementations in textile composite manufacturing. This work demonstrates how systematic digital integration within 3D weaving can bridge textile processing science with composite certification requirements and industrial scalability, offering a transferable framework for next-generation composite manufacturing systems.

Keywords: 3D weaving, 3D woven composites, digital thread, Jacquard weaving, smart manufacturing, Industry 4.0, process monitoring, real, time data acquisition, data integration, data pipeline, signal processing

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