

Redefining Verification Velocity in Embedded Medical Devices Through Scalable Test Automation Using AI-Enhanced Testing Techniques and Hardware-in-the-Loop Capabilities

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Abstract:

The rapid evolution of embedded medical devices has significantly increased system complexity, intensifying the need for faster yet rigorous verification processes that ensure safety, reliability, and regulatory compliance. Traditional verification approaches struggle to scale under growing functional requirements, tight development schedules, and stringent medical standards. This paper presents a unified scalable verification framework that redefines verification velocity through the integration of automated test execution, artificial intelligence (AI)-enhanced test generation, and advanced Hardware-in-the-Loop (HIL) capabilities for embedded medical systems. The proposed architecture is built on four cohesive layers: (i) a domain-specific language that formalizes clinical, safety, and regulatory requirements into executable verification logic; (ii) an AI-assisted test generation engine that expands test coverage by identifying edge cases and latent failure scenarios; (iii) an HIL orchestration layer that enables synchronized validation of embedded software behavior against real-time physical device responses; and (iv) an adaptive reporting and documentation engine that generates traceable, audit-ready verification artifacts aligned with medical regulatory standards. Experimental results from a representative embedded medical device platform demonstrate substantial improvements in verification throughput, test coverage, and system robustness compared to conventional manual and simulation-only approaches. The framework further introduces automated recovery mechanisms, continuous real-time state monitoring, and exception-handling workflows tailored for safety-critical medical interfaces. By unifying intelligent automation with hardware-coupled validation, this work establishes a practical and scalable paradigm for next-generation verification of embedded medical devices, accelerating development cycles while strengthening product quality and patient safety.

Keywords:

Artificial intelligence (AI)-enhanced test generation, embedded medical devices, hardware-in-the-loop (HIL), verification automation.