

Supplementary Material for:
BioSync-AI: A Rule-Based Autonomous Bioelectronic Wearable Patch for
Real-Time Closed-Loop Control in Simulation

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Supplementary Tables

The following tables provide comprehensive background analysis and safety modeling data supporting the primary manuscript.

Table S1: Comprehensive Summary of Prior Art vs. BioSync-AI			
System Category	Key Representatives	Primary Capabilities	Limitations Addressed by BioSync-AI
Consumer Wearables	Apple Watch, Fitbit, Garmin	Heart rate, SpO2, PPG monitoring; smartphone alerts	Completely passive; no drug delivery; cloud/smartphone dependent; no on-device reasoning.
Epidermal Bioelectronics	Rogers <i>et al.</i> , Malliaras	Skin-conformable sensing; high signal fidelity; OECT transducers	Open-loop monitoring only; no automated actuation or edge AI reasoning; no safety interlocks.
Traditional Infusion Pumps	Medtronic 780G, Omnipod 5, Tandem t:slim	Continuous insulin delivery; basic PID/MPC algorithms	High response latency (>400 ms); susceptible to dose stacking; rigid rule-based control logic.
Cloud-AI Health Telemetry	BioIntelliSense, Current Health	Cloud-scale LLM processing; remote patient monitoring	Network latency (>300 ms); signal loss in rural/disaster zones; patient data privacy concerns.
BioSync-AI (This Work)	ESP32-S3 + LangGraph + BioBERT-Tiny	On-device agentic AI; sub-15 ms closed-loop dosing; dual fail-safe interlocks	First unified autonomous wearable patch integrating sensing, reasoning, and actuation with hardware safety.

Table S2: Failure Mode and Effects Analysis (FMEA) for BioSync-AI Wearable Patch

Subsystem	Failure Mode	Root Cause	S	O	D	RPN	Mitigation Strategy
Substrate	Physical tearing / detachment	Mechanical shear stress	9	3	1	27	Hardware interlock forces 0° valve closure in $< 1.5 \mu\text{s}$.
Bio-Sensor	Signal drift / noise spikes	Motion artifacts or electrode degradation	6	4	2	48	128-sample moving average filter + BioBERT anomaly confidence check.
AI Engine	Corrupted inference state	SRAM bit-flip or buffer overflow	8	2	2	32	Hardware Watchdog Timer (WDT) resets MCU in 100 ms; safe defaults.
Actuator Servo	Mechanical valve stall	Fluid crystallization or microchannel clog	7	3	3	63	Current-sensing stall detection + biological-patience velocity limit.
Power Supply	Battery voltage depletion	Extended high-dose operation	5	3	2	30	Low-voltage cutoff trigger; audible alert warning.
Communication	I ² C bus lockup	EMI interference or clock stretch timeout	4	2	2	16	Bus reset routine; local display status fallback.