Claims

Telemetry-Feed Integration Suite for the TraceLoop ICU Platform

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Independent System Claim

1. A critical-care automation system comprising:

   (a) a secure control bus that couples to a plurality of therapy actuators including at least one heparin-infusion pump, protamine-infusion pump, intravenous-fluid pump, neuromuscular-blocking-agent (NMBA) pump, ventilator controller, enteral-feeding pump, and electrically-driven hospital bed;

   (b) a sensor-ingestion layer having protocol adapters configured to receive physiological telemetry over any of HL7, MQTT, Bluetooth Low Energy, serial or parallel electrical busses, each adapter outputting a time-stamped message;

   (c) a normalization engine that maps every received message into a row of a fifteen-column factor schema stored in a relational database, the schema identifying a factor ID, numerical value, units, time-to-harm, harm-severity, conflict-group, priority_over, mutually_exclusive, and requires_ok fields;

   (d) a real-time arbitration engine that, every control cycle, topologically sorts the factor rows according to said priority_over, mutually_exclusive and requires_ok fields, selects at most one row per conflict-group as a winner and issues an actuator command derived from that winning row;

   (e) a watchdog and guard-rail layer that suppresses or reverts actuator commands when a factor row exceeds pre-defined hard limits or loses data freshness; and

   (f) six telemetry-integration modules implemented as respective factor rows that publish:

      (i) Anti-factor Xa activity,

      (ii) head-of-bed (HOB) angle,

      (iii) passive-leg-raise (PLR) fluid-responsiveness flag,

      (iv) train-of-four (TOF) ratio,

(v) prone-position status and timer, and

(vi) spontaneous-breathing-trial (SBT) readiness flag,

each module being selectable between a Full build that enables closed-loop actuation of at least one actuator named in element (a) and a Lite build that generates decision-support alerts without actuation,

wherein the arbitration engine applies the same conflict-graph logic to all six modules so that cross-channel safety is deterministically enforced even when the modules are compiled in different build combinations.

Dependent Claims – Feed-Specific Logic

2. The system of claim 1 wherein the Anti-factor Xa module assigns a higher harm-severity score than a heparin-infusion factor row and declares priority_over the heparin row, the heparin row further containing requires_ok = Anti-Xa, such that a protamine command issued by the Anti-Xa row automatically blocks simultaneous heparin infusion.

3. The system of claim 1 wherein the HOB-angle module resides in a BED conflict-group and, in its Full build, transmits a raise-bed command when the angle value falls below a threshold of 30 degrees for longer than a configurable grace period.

4. The system of claim 1 wherein the PLR module:

   (a) shares the BED conflict-group,

   (b) commands the bed to lower the torso and elevate the legs,

   (c) computes stroke-volume change ΔSV from an arterial-line or bioreactance feed, and

   (d) sets a Boolean fluid_responsive field to TRUE when ΔSV ≥ 10 %, the Boolean being referenced by an IV-fluid-bolus factor row through requires_ok = fluid_responsive.

5. The system of claim 1 wherein the TOF module:

   (a) ingests twitch-amplitude data from a thumb accelomyograph,

   (b) derives a TOF ratio at least every 30 seconds, and

   (c) feeds the ratio into an NMBA-pump row that executes a proportional-integral-derivative

algorithm constrained to ±5 % rate change per update and disabled automatically when a sedation-loop requires_ok field evaluates FALSE.

6. The system of claim 1 wherein the prone-position module resides in the BED conflict-group, starts a countdown timer when position = PRONE, pauses an enteral-feeding-pump row by asserting priority_over that row, and raises a high-severity alert when the timer exceeds a preset duration threshold.

7. The system of claim 1 wherein the SBT-readiness module evaluates an AND-gate of ventilator $FiO_2 \leq 0.5$, PEEP ≤ 8 cm H_2O, $SpO_2 \geq 92$ %, vasopressor dose below a configurable limit, sedation-loop state LIGHT, and TOF ratio ≥ 0.9 for at least ten consecutive minutes, the module publishing a TRUE readiness flag that gates a ventilator-mode-switch row through requires_ok = SBT_READY.

8. The system of any preceding claim wherein the arbitration engine writes every sensor value, rule evaluation, override event, and actuator command into an immutable, hash-chained audit ledger.

9. The system of any preceding claim wherein loss of telemetry for any module beyond a watchdog interval causes the guard-rail layer to (i) freeze the associated factor value, (ii) deactivate its actuator row if running in Full mode, and (iii) raise a deterministic fallback alert.

10. The system of any preceding claim wherein each module exposes a build_mode flag stored in the relational database; the flag is checked at compile time so that a Lite build suppresses generation of actuator-intensity fields while preserving risk-score computation for alert prioritisation.

Independent Method Claim

11. A method of operating a critical-care automation system, the method comprising:

(i) receiving telemetry for Anti-Xa, HOB angle, PLR manoeuvre, TOF ratio, prone status, and SBT readiness over mixed HL7, MQTT, BLE, and serial links;

(ii) normalising each telemetry item into a fifteen-column factor row;

(iii) assigning to each factor row at least one of: a harm-severity value, a conflict-group identifier, a priority_over edge, a mutually_exclusive edge, and a requires_ok edge;

(iv) on every control cycle, performing a topological sort of the factor rows and selecting per conflict-group a highest-priority row whose requires_ok conditions are satisfied;

(v) issuing, from the selected rows, actuator commands that include at least one of: adjusting

heparin or protamine rate, moving the hospital bed, altering an intravenous-fluid or NMBA infusion, pausing an enteral-feeding pump, or switching a ventilator mode;

(vi) inhibiting an actuator command and generating an alert when a guard-rail limit is reached or a mutually_exclusive edge is detected; and

(vii) cryptographically recording steps (i) through (vi) in an audit ledger.

Additional Dependent Method Claims

12. The method of claim 11 wherein step (v) further comprises preventing a heparin-infusion command when the Anti-Xa factor row is the selected winner in its conflict-group.

13. The method of claim 11 wherein step (v) comprises initiating a passive-leg-raise by bed actuation, computing ΔSV, and permitting a fluid-bolus command only if $\Delta SV \geq 10\ \%$.

14. The method of claim 11 wherein, during an SBT trial, any occurrence of $SpO_2 < 88\ \%$ or respiratory rate > 38 breaths min^{-1} for more than 30 seconds triggers an automatic ventilator reversion command under step (vi).

15. The method of claim 11 wherein a clinician may at any time invoke a manual BLOCK override on any factor row, the override being logged and causing the arbitration engine to demote that row until the override expires or is cleared.

Apparatus Claim – Telemetry Adapter

16. A telemetry-adapter module comprising firmware-configurable transceivers that translate HL7 v2, BLE GATT, MQTT, and RS-232 frames into a unified JSON payload having keys id, value, units, timestamp, and quality, the module further writing the payload into a shared memory buffer readable by the normalization engine of the system of claim 1, thereby enabling plug-and-play addition of new telemetry feeds without modifying arbitration logic.

Computer-Readable Medium Claim

17. A non-transitory computer-readable medium storing instructions that, when executed by a processor of a critical-care controller, cause the processor to perform the method of any of claims

11–15.