Claims

Independent Apparatus Claim

1. A multimodal optical-thermal patient-monitoring module for use with a closed-loop critical-care automation system, the module comprising:

   (a) a housing configured for mounting above a patient bed and containing—

      (i) a visible-light camera,

      (ii) a near-infra-red (NIR) camera with on-axis NIR illumination, and

      (iii) a long-wave-infra-red thermal imager;

   (b) an embedded edge-computing processor arranged to receive synchronized image streams from the cameras and to execute on-device inference algorithms that convert the image streams into numerical physiological metrics including at least a pain-expression score, respiratory rate, skin-perfusion index, edema map, line-integrity flag, posture state, and eye-state indicator;

   (c) a secure communication interface that publishes the numerical physiological metrics—without transmitting raw image frames—onto a protected control bus of the automation system;

   (d) a privacy subsystem comprising a physical lens cover and a software interlock that disable image acquisition during designated privacy periods; and

   (e) a watchdog circuit that, upon detecting loss of video quality or processor fault, asserts a fault flag over the communication interface to enable deterministic sensor-only fallback by the automation system.

Independent System Claim

2. A closed-loop intensive-care automation system comprising:

(a) the monitoring module of claim 1;

(b) one or more therapy actuators selected from infusion pumps, ventilator controllers, environmental-control devices, and alert generators, each addressable over a secure control bus;

(c) a real-time arbitration engine having a multi-tier control hierarchy including—

(i) a vital-override layer that executes immediate life-saving interventions,

(ii) a guard-rail layer that constrains therapies within safety limits, and

(iii) an optimiser layer that modulates therapies to achieve target patient states;

(d) a rule database that maps the numerical physiological metrics from the monitoring module to actions in at least one of the hierarchy layers; and

(e) an immutable audit ledger that records every metric, rule evaluation, actuator command, and clinician override,

wherein the arbitration engine, upon receiving a metric published by the monitoring module, selects a control layer according to the rule database and issues corresponding commands to the therapy actuators, the audit ledger storing the provenance linking each issued command to the published metric.

Independent Method Claim

3. A method for camera-enhanced adaptive dosing in an intensive-care environment, the method comprising:

(i) acquiring synchronized visible-light, NIR, and thermal images of a patient using the monitoring module of claim 1;

(ii) executing, on the embedded processor, machine-learning algorithms that convert the synchronized images into the numerical physiological metrics;

(iii) transmitting the numerical physiological metrics to the arbitration engine of the automation system without transmitting raw images;

(iv) evaluating, in real time, a ruleset that assigns each numerical physiological metric to a

selected layer of the multi-tier control hierarchy;

(v) issuing, from the selected layer, an actuator command that adjusts at least one therapy parameter when a metric satisfies a predetermined threshold;

(vi) detecting a loss-of-image-quality condition and, in response, suppressing further metrics from the monitoring module and continuing therapy control based on non-image sensors; and

(vii) recording each metric, rule evaluation, actuator command, and fallback event in the immutable audit ledger.

Dependent Claims (illustrative)

4. The module of claim 1 wherein the embedded processor is an NVIDIA Jetson Xavier or Orin-class device and the inference algorithms are containerized for on-device execution.

5. The module of claim 1 wherein the thermal imager has a spatial resolution of at least 320 × 240 pixels and is calibrated to provide ±0.3 °C temperature accuracy at the patient surface.

6. The module of claim 1 wherein the published physiological metrics are formatted as fifteen-column TraceLoop factor records that include a confidence score and timestamp.

7. The system of claim 2 wherein a pain-expression score exceeding a preset limit is routed to the optimiser layer, which increments an opioid-infusion rate by a micro-dose constrained by a guard-rail maximum.

8. The system of claim 2 wherein detection of paradoxical respiration by the monitoring module is routed to the vital-override layer, which actuates an antagonist drug cartridge and pauses ongoing opioid infusion.

9. The system of claim 2 wherein detection of an IV-line disconnection by the monitoring module is routed to the vital-override layer to halt an associated infusion pump and raise a high-priority alarm.

10. The system of claim 2 wherein a trend of increasing edema metric over successive time windows adds a linear constraint in the guard-rail layer that limits additional crystalloid-fluid infusion.

11. The system of claim 2 wherein the arbitration engine masks out any rule that depends on a physiological metric flagged as faulty by the watchdog circuit of the monitoring module.

12. The method of claim 3 wherein the actuator command in step (v) is a ventilator parameter adjustment that increases inspiratory pressure support when the respiratory-effort metric exceeds a preset threshold.

13. The method of claim 3 further comprising presenting, on a clinician-override interface, a human-readable explanation that links each actuator command to the originating physiological metric from the monitoring module.

14. The module of claim 1 wherein the privacy subsystem encrypts all stored image data using hardware-rooted keys and permanently deletes raw frames after metric extraction.

15. The module of claim 1 further comprising a depth sensor co-aligned with the visible-light camera, the depth sensor providing three-dimensional posture information included in the numerical physiological metrics.

16. The system of claim 2 wherein the rule database assigns a first priority weight to camera-derived respiratory metrics and a lower priority weight to camera-derived posture metrics, enabling the arbitration engine to resolve simultaneous control requests.

17. The system of claim 2 wherein the audit ledger is implemented as a hash-chained sequence of blocks stored redundantly on at least two physically separate nodes.

18. The method of claim 3 wherein, during the loss-of-image-quality condition, the arbitration engine automatically lowers opioid-infusion limits to pre-defined conservative levels until image quality is restored.

19. The system of claim 2 wherein clinician activation of a manual override suppresses all camera-driven optimiser actions for a selectable duration without disabling the vital-override pathway.

20. The module of claim 1 wherein the secure communication interface comprises an isolated CAN-FD transceiver that transmits metrics at a deterministic 100 Hz cycle, each frame containing a cyclic-redundancy-check field.