AI Based Industrial Safety Predictive Hazard System

Karnam Gururaj[1], Chaithanya Patel[2], Dushanth B R[3], Hemanth D[4], Tejas N[5]
[1]*Assistant Professor Department of Electronics & Communication Engineering. A P S College of Engineering Bangalore, India*
[2, 3, 4, 5] *Department of Electronics & Communication Engineering. A P S College of Engineering Bangalore, India*

***Abstract*—Industrial demonstration models often address gas leakage, excessive temperature, visual fire recognition and worker health as isolated tasks. This paper presents an integrated, low-cost warehouse safety prototype that brings these functions into a common monitoring and response architecture. A temperature-humidity sensor and a gas-sensing module supply environmental readings to a microcontroller; a USB webcam provides video to a laptop-hosted fire-detection model; and a MAX30102 optical module supports experimental pulse-rate and oxygen-saturation monitoring. A two-channel relay operates a ventilation fan and a water pump, while a web interface is intended to present sensor values, hazard categories and actuator states. The prototype is documented from the project scope and photographs, with an example ESP32 interface, circuit drawings and a repeatable validation protocol. Because calibrated measurements, trained-model evaluation and complete electrical traceability were not supplied, this study reports the integration design and test method rather than claiming validated detection accuracy. The proposed platform is suitable for teaching sensor fusion, inter-device communication and safety-response logic, but it is not a certified industrial fire-protection or medical device.**

***Index Terms*—Industrial safety, Internet of Things, fire detection, computer vision, ESP32, gas monitoring, MAX30102, relay control, warehouse demonstrator.**

I. INTRODUCTION

A warehouse may appear stable while heat accumulates near equipment, a gas sensor responds to a changing atmosphere, or a worker experiences an abnormal physiological reading. A useful monitoring system must turn these disconnected observations into an understandable operational state and, where appropriate, a bounded response. The proposed demonstrator addresses this need using environmental sensors, webcam analysis, relay-driven actuators and a shared user interface.

The attached project brief specifies an open-top 3D-printed industrial warehouse, temperature and gas monitoring, webcam-based visual fire recognition, automatic ventilation and water spraying, and wearable worker-vital monitoring. It also identifies a live dashboard and Normal, Warning and Danger conditions as desired outputs.

The accompanying photographs show a blue enclosure, white mounting surface, two-channel relay, power regulator, pump, fan, DHT11 module and USB webcam. A second photographed assembly forms part of the same project; it appears to contain a separate controller and power distribution board, but the obscured device markings do not support a definitive pin-level reconstruction.

This work contributes a coherent integration design, proposed electrical interfaces, explicit safety boundaries, a testable decision algorithm and an evidence-aware documentation approach. No independent field results, certified alarm characteristics or clinical comparisons are assumed.

II. RECENT RELATED WORK

Recent research shows that visual fire analysis, low-cost sensor networks and wearable monitoring each offer valuable capabilities but have different reliability limits. Zhang et al. [1] developed an improved YOLOv8n approach for fire and smoke in smart factories, highlighting the importance of smoke as well as flame.

Li et al. [2] investigated industrial and mining fire detection using an enhanced YOLO architecture. Both studies support the use of vision models in complex environments; neither provides performance evidence

for the webcam and laptop configuration of this prototype.

Sozol et al. [3] proposed an optimized YOLOv5 model for indoor fire and smoke images and reported results on their own dataset. Deshpande et al. [4] studied transfer-learning-based fire and smoke recognition under varied industrial conditions.

More recently, Guan et al. [5] described a YOLOv11n-derived model for complex warehouse scenes, with attention to small flames and efficient inference. These papers suggest that model selection should account for smoke appearance, background clutter, lighting and computational budget rather than rely only on headline benchmark scores.

For sensing and alerting, the 2025 Procedia Computer Science paper on fire and gas recognition [6] illustrates how embedded sensors can be linked to remote monitoring. Sadeghi et al. [7] studied a MAX30102-based wearable platform with intelligent alerting. Their work motivates physiological integration, but its more advanced processing and evaluation must not be attributed to this simpler device.

The gap addressed here is the practical co-design of environmental sensing, visual events, two relay-controlled actuators and worker vitals in a single demonstrator with transparent validation requirements.

III. SYSTEM ARCHITECTURE

A. Functional Arrangement

The sensing layer comprises the DHT11, an MQ-family gas sensor (MQ-2 is used only as an example in the reference circuit), and a MAX30102 optical heart-rate/SpO_2 breakout. A microcontroller samples these signals, maintains device status and drives the fan and pump through separately switched relay contacts.

The webcam connects by USB to a laptop, where a fire model can classify successive frames and forward a time-stamped event to the embedded controller. The same host can serve a dashboard and store events. This separation is important: an ordinary USB webcam cannot be connected to arbitrary ESP32 GPIO pins.

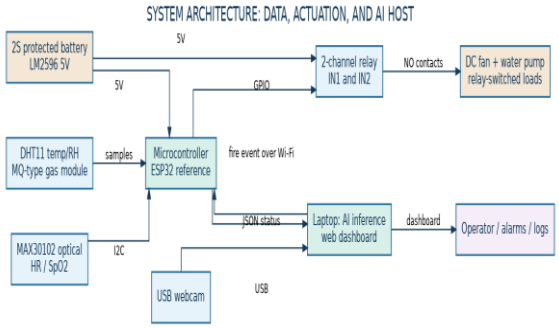


Fig. 1. Conceptual data and actuation paths; the webcam is on the laptop, not on an MCU pin.

B. State Model and Communication

Environmental data and camera events have different failure modes. Temperature, relative humidity and the gas-sensor signal are tagged with sample timestamps; camera detections include inference confidence and an event age. The operator interface separates Normal, Warning and Danger status from component faults.

A stale camera message must not indefinitely maintain or retrigger a water pump. The proposed decision logic uses a bounded actuation interval, configurable thresholds, a short persistence window and a manual emergency stop. These values must be finalized by risk assessment, not selected as universal safe limits.

IV. HARDWARE AND MATERIALS

A. Electronic Components

Table I combines the requested component inventory with the photographed elements. Since the original board model is unreadable, the pin map in the next section is explicitly an ESP32 DevKit reference design rather than proof of the installed controller. Similarly, the gas-sensor family cannot be confirmed from the photographs.

Table 1: Electronic Components and Intended Functions

Component	Qty	Engineering purpose
Microcontroller development board	1	Sensor interface; relay commands; telemetry
2-channel relay module	1	Isolated switching contacts for fan/pump
LM2596 buck converter	1	Regulated supply from battery pack

DC water pump + tube	1 each	Demonstration water-spray loop
DC cooling fan	1	Forced airflow / ventilation response
2-cell 18650 holder	1	Portable power source (cell count to verify)
DHT11	1	Ambient temperature and humidity
Gas sensor, MQ family	1	Relative gas/smoke response, not selective ppm
MAX30102 breakout	1	Experimental pulse / SpO2 acquisition
USB webcam (visible)	1	Laptop-based vision input

B. Mechanical Components

The blue 3D-printed enclosure or tray, white mounting base, sensor mounting stand, fan bracket and pump mounting base establish repeatable component positions. Jumper leads and connectors join the electronic modules; the flexible tube routes water away from the circuit. The mounting arrangement should physically separate wet tubing from electrical terminals, support cable strain relief and leave access for the main battery disconnect and power tests.

One photograph clearly shows a two-cell holder, whereas another holder appears to have an additional cell position. The latter is a visual observation only. The final design must identify the populated series cell count before choosing a battery-management system or setting the power converter.

C. Sensor and Actuator Limits

The DHT11 gives coarse environmental indications and is not a calibrated industrial temperature or humidity transmitter. MQ-family modules generally require preheating, baseline measurements and a suitable interpretation of the analog output; an uncalibrated voltage must not be described as a certified gas concentration.

The MAX30102 performs optical photoplethysmography and is sensitive to finger placement, movement and perfusion. Its readings are for educational demonstration rather than medical diagnosis.

The relay contacts should be used to switch suitable low-voltage motor loads, not to power a motor from a GPIO. Because pumps and fans can draw substantial starting current, rated load current, cable size, contact protection and inductive transient suppression must be checked. Water spraying should never be presented as a safe method for energised electrical fires.

V. ELECTRICAL DESIGN

A. Power Architecture

For the requested two-cell series arrangement, the nominal lithium-ion pack is approximately 7.4 V and the maximum fully charged voltage is approximately 8.4 V, subject to the actual cell specification. A correctly rated 2S battery-management/protection circuit and fuse should be placed upstream of the LM2596 converter.

With the power removed from all downstream boards, the converter is adjusted and measured at 5.0 V. The regulated rail powers only devices whose rated voltage and current are compatible; the microcontroller supplies a 3.3 V rail to suitable sensors if its regulator capacity allows.

For an assumed 5 V gas-sensor analog output and a 3.3 V ADC, one reference interface uses a 12 kΩ series resistor and a 22 kΩ resistor to ground. The maximum ADC voltage is approximately $5 \times 22/(12+22) = 3.24$ V. Resistor tolerances, ADC calibration and transient margins must still be evaluated; direct 5 V AO-to-ESP32 connection is not acceptable. MAX30102 breakout-board power requirements differ across vendors, so its VIN and I²C pull-up voltages must be inspected.

B. Proposed Reference Pinout

Table 2: Esp32 Example Connection Map (Not Verified Photo Wiring)

Interface	Pin	ESP32 / supply
DHT11	DATA, VCC, GND	GPIO4, 3V3, GND
MQ-2 example	AO, VCC, GND	GPIO34 via divider, 5V, GND
MAX30102	SDA, SCL	GPIO21, GPIO22
MAX30102	VIN, GND	3V3*, GND
Relay CH1	IN1	GPIO26 (fan)
Relay CH2	IN2	GPIO27 (pump)
Relay module	VCC, GND	5V*, GND
Webcam	USB	Laptop USB host

The asterisks indicate module-specific checks: some relay boards require level-shifted inputs or a separate relay supply, while some MAX30102 boards have

their own regulation. Relay CH1 normally-open contacts switch the fan positive lead; CH2 normally-open contacts switch the pump positive lead. Each motor returns to the correctly rated source return. Where a shared 5 V supply is used, its converter and battery must withstand simultaneous load current.

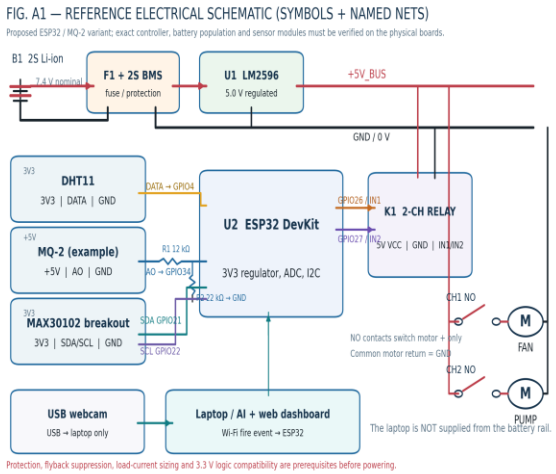


Fig. 2. Reference schematic with named power nets and relay contact symbols; full-size drawing appears in Appendix A.

VI. SOFTWARE AND DECISION ALGORITHM

A. Implementation Software

An ESP32 version can be developed using Arduino IDE or PlatformIO with a DHT sensor library, a MAX3010x library, ADC calibration routines and Wi-Fi networking. Laptop software can use Python, OpenCV and a version-controlled fire-recognition model; a lightweight Flask or similar server can expose a dashboard and exchange event messages.

These tools are proposed implementation choices. The project quotation calls for embedded firmware, webcam image processing, a real-time data interface, alarms and event logging but does not identify the completed software stack.

B. Hazard-Response Algorithm

At startup, the controller configures outputs to a known state, validates sensors and tests communications before accepting remote events. At each sampling cycle it records temperature, humidity, gas-sensor ADC level and wearable data quality. A fan request is raised when the configured temperature threshold or gas threshold is exceeded for an accepted persistence period; it is cleared only after hysteresis conditions are met.

A pump request is accepted solely from a fresh, authenticated camera-fire event (or an authorized manual test), subject to an actuation timeout and dry-run safeguards. Missing or invalid data produces a fault indication instead of fictitious zero values.

For a traceable implementation, let

$F = (T > T_{high})$

OR

$(G > G_{high})$

and

$P = V_{fire}$ AND $Age_{fire} < \tau$ AND enable.

Here F is a ventilation request, P is a spray request, T and G are valid environmental observations, and V_{fire} is a temporally confirmed vision event.

These expressions define proposed logic only; thresholds, sampling periods and τ require validation. A risk score may support prioritization, but a trained predictive model cannot be claimed without time-series training data and prospective evaluation.

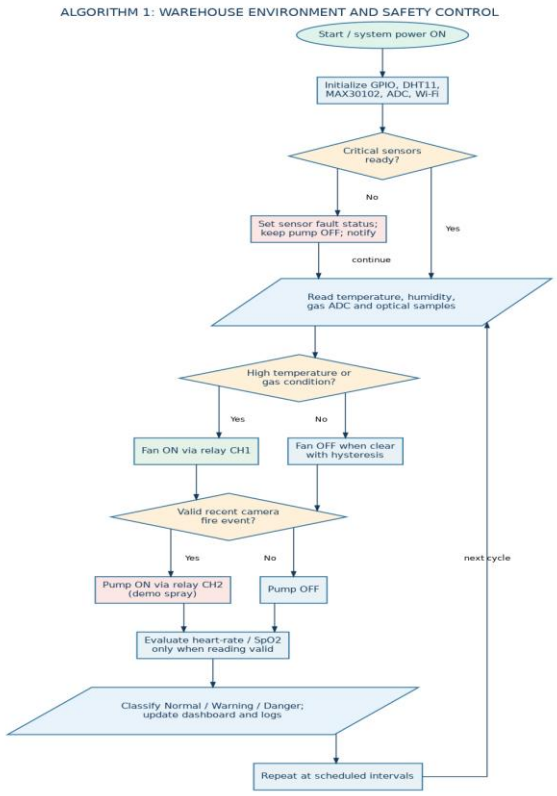


Fig. 3. Proposed hazard monitoring and response logic using terminal, process, decision and data symbols.

VII. IMPLEMENTATION AND EVALUATION METHOD

A. Physical Assembly

The photographed prototype places the sensing and relay hardware in a white-and-blue display structure while locating the fan, pump and webcam around the warehouse model. The second photographed electronics board appears to carry the supply/controller wiring.

These images support physical assembly evidence but do not establish electrical correctness or functional operation. Integration therefore proceeds from continuity checks and isolated low-voltage power verification to individual sensor tests, contact tests with loads disconnected, and finally supervised end-to-end scenarios.

B. Verification Protocol

A reproducible evaluation should record sensor update rate, data-loss fraction, webcam processing latency, false-alert frequency, fan response time, pump activation and cutoff time, and power-rail behavior during motor startup. Environmental variables should be compared with suitable reference instruments.

Human pulse and SpO_2 readings require motion-controlled conditions and a calibrated comparator; unvalidated biomedical alarms should remain advisory. All fire/smoke demonstrations must use safe simulated material and avoid open flames near batteries and electronics.

Table 3: Acceptance Test Matrix / Results Status

Scenario	Expected check	Status
DHT11 ambient read	Fresh T/RH & timestamp	Not reported
Gas-sensor stimulation	ADC rise; warning/fan	Not reported
Camera test imagery	Time-stamped fire event	Not reported
Fan command	Relay CH1 switching	Not reported
Pump command	Relay CH2 cutoff	Not reported
MAX30102 reading	Quality-gated HR/SpO2	Not reported
Battery load transient	5V stable under load	Not reported

C. Results and Discussion

The documented outcome at the time of writing is an assembled physical demonstrator, the stated functional architecture and a proposed circuit-level and software-level implementation. No supplied dataset establishes flame classification precision, recall, alert latency, motor current, battery runtime, sensor error or wearable measurement accuracy. It would therefore be misleading to report numerical performance or to label the system a field-tested predictive safety product.

Even without those measurements, the integration highlights several design insights. Visual fire recognition adds a spatial cue that a single point sensor cannot provide, while local temperature and gas inputs remain useful when the webcam is obstructed. Separating pump and fan control into independent relays prevents one response from implicitly demanding the other.

Timestamped data improves fault diagnosis and helps distinguish hazards from network outages. Conversely, a single gas-sensor element cannot identify different industrial gases reliably, and a webcam can be fooled by illumination, reflections or occlusions. These limitations determine the priorities for controlled testing and safe extension.

VIII. SAFETY, LIMITATIONS AND FUTURE WORK

The prototype is intended for model-warehouse instruction and demonstration, not for deployment as an independent life-safety installation. A production system would require certified sensors and alarm equipment, electrical protection, a fail-safe architecture, maintained power, commissioning procedures, documented maintenance, fire-code review and human supervision. T

he proposed battery pack also requires cell matching, a correct charger, protection electronics and thermal management. Wet and dry portions of the assembly should be separated by physical barriers.

Future work can establish a labeled fire/smoke image dataset captured under actual model lighting, test multiple detector families, quantify event-to-actuator latency and add cross-sensor consistency checks.

The physiology branch could be implemented as a detachable wearable with secure identity and consent-aware handling of personal data. A clearer engineering distinction between threshold-based hazard prevention

and genuinely predictive risk modelling would permit defensible claims as the system matures.

IX. CONCLUSION

This paper has translated the project brief and two photographed assemblies into a unified, testable engineering design for an AI-assisted industrial safety demonstrator. It integrates environmental readings, camera-based fire events, independent ventilation and water-pump actuation, optical worker-vital sensing and an operator dashboard. Proposed circuit drawings identify power protection, logic-voltage compatibility and relay switching paths, while the test matrix identifies evidence still required. The most useful outcome is not an unverified accuracy number but a clear route from a physical prototype to repeatable, safety-conscious evaluation.

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