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An IoT Gas, Flame and Environment Monitoring Node for Explosion-Risk Detection

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Abstract

This paper reports an IoT monitoring node built to demonstrate early detection of explosion-risk conditions, and assesses it against the requirements that apply to gas detection in flammable atmospheres. The node combines a metal-oxide combustible-gas sensor, a flame sensor read as an analogue range, a temperature and humidity sensor, an ESP8266 controller, a relay-driven ventilation actuator and a cloud dashboard. The telemetry actually recorded is reported exactly as captured: a single snapshot showing 32 degrees Celsius, 82 % relative humidity and a gas channel reading zero, together with a demonstrated fire-detected notification. The assessment then states plainly what such a record can support. Because the gas channel was never exposed to certified calibration gas, its output remains an uncalibrated ratiometric value, not a concentration. Therefore, no LEL or ppm reading or alarm threshold is justified; zero only indicates no response, not gas absence.
Detection time, minimum detectable concentration, cross-sensitivity, warm-up behaviour and drift were likewise not measured. Metal-oxide sensor response is further shown from the literature to depend strongly on humidity, which the recorded 82 % places in the region where that dependence is largest. This revision adds two quantitative elements. First, the alarm bands the paper discusses are expressed in absolute units using published explosive limits, so that the concentration range an instrument would have to span is stated rather than left abstract: a low alarm at 20 % of the limit corresponds to 10,000 ppm for methane and 4,200 ppm for propane. Second, the ventilation relations are evaluated, showing that a relay-driven fan dilutes an enclosure on a timescale of tens of minutes, which places it firmly among slow mitigations rather than protective responses. The paper separates built-and-demonstrated capability from unmeasured capability, and states the certification and enclosure requirements that a node intended for a genuinely hazardous area must satisfy but which this prototype does not address.

Nomenclature

Symbol	Meaning
C	Combustible gas concentration (ppm or per cent of the lower explosive limit)
LEL	Lower explosive limit of the target gas (% v/v)

R_s, R_0	Sensing resistance and baseline resistance in clean air (Ω)
A, α	Gas-specific constants of the metal-oxide response law
T_{90}	Time to reach 90 % of the final response after a step change (s)
τ_{det}	Detection-to-alarm time (s)
t_{proc}, t_{comm}	Processing and communication delay (s)
T_a, RH	Ambient temperature (degrees Celsius) and relative humidity (%)
P_d, P_{fa}	Detection and false-alarm probability
C_{min}	Minimum detectable concentration
Q_v, V_r	Ventilation volumetric flow (m^3/s) and enclosed volume (m^3)
n, t_{dil}	Air-change rate (per hour) and dilution time (h)

Introduction

Fire and explosion are the dominant catastrophic risks in oil and gas processing, and gas detection is one of the primary engineered safeguards against them [1], [2]. That role imposes requirements which are unusually strict and unusually specific: a gas detector is not judged by whether it produces a number, but by whether that number is traceable to a calibration, whether the instrument responds within a bounded time, whether it retains sensitivity under the humidity and temperature of its installation, and whether its enclosure is certified for the hazardous area in which it is mounted [5].

This paper reports an IoT monitoring node of the type widely built for teaching and demonstration: a metal-oxide gas sensor, a flame sensor, a temperature and humidity sensor and a relay-driven ventilation output, all mediated by a Wi-Fi microcontroller and published to a cloud dashboard [6], [7]. The node functions. The purpose of this paper is to state precisely which of the requirements above it meets, which it does not, and what would have to be measured for the difference to close.

1. Problem Statement

IoT gas-monitoring prototypes are reported in large numbers, and they almost invariably present a dashboard reading as though it were a concentration. It is not: a metal-oxide sensor produces a resistance ratio which becomes a concentration only after calibration against a known gas mixture. The consequence is a literature of demonstrations that cannot be compared with each other or with an instrument, because none is traceable. Meanwhile the process-safety literature specifies exactly what traceability requires. Little work connects the two by taking a transparently reported prototype and measuring it against the actual requirement.

2. Objectives

The specific objectives of the work are as follows:

- To build a node combining metal-oxide gas sensing, flame sensing, temperature and humidity measurement, relay-driven ventilation and cloud alerting.
- To report the telemetry exactly as captured, including a gas channel reading zero, with no interpretation added.
- To establish precisely why that channel cannot be expressed as a concentration, and what a zero reading does and does not establish.
- To express the alarm bands in absolute units using published explosive limits, so that the measurement range an instrument would have to span is stated rather than left abstract.
- To evaluate the ventilation relations numerically, so that the timescale on which a relay-driven fan acts is known rather than assumed.
- To state the certification, bounded-response and fault-revelation requirements a hazardous-area node must satisfy, and the distance between those and this prototype.

3. Scope and Delimitation

The study covers the construction of the node, the relations governing gas detection and ventilation, the reading of the single recorded snapshot, and the specification of the qualification steps that were absent. It excludes any claim of gas concentration, alarm threshold, detection time, minimum detectable concentration, cross-sensitivity, drift, detection or false-alarm probability, and any claim of suitability for installation in a classified hazardous area. The machine-learning, SCADA and distributed-deployment features named in the source design documentation were not built and are excluded from every claim. No safety claim of any kind is made for this device.

4. Contributions

1. A transparent report of the telemetry recorded, including the gas channel reading zero, with no interpretation added.
2. A precise statement of why that channel cannot be expressed as a concentration,

and of what a zero reading does and does not establish.
3. Identification of the humidity dependence of metal-oxide sensing as directly relevant at the recorded 82 % relative humidity.
4. Consolidation of the concentration, alarm-band, response-time and ventilation relations governing gas detection.
5. An absolute-units statement of the alarm bands, new to this revision, using published explosive limits, which fixes the concentration range a calibrated instrument would have to span.
6. A numerical evaluation of the ventilation relations, new to this revision, which establishes that a relay-driven fan acts on a timescale of tens of minutes.
7. An explicit statement of the certification, response-time and availability requirements a hazardous-area node must satisfy, and of the gap between those and the prototype.

The remainder of the paper is organised as follows. Section II reviews related work and fixes the reference values. Section III gives the governing relations. Section IV describes the prototype and the method. Section V reports the recorded data and its honest reading. Section VI discusses the findings, Section VII states the certification and availability gap, and Section VIII the limitations. Section IX gives the proposed architecture and qualification plan, and Sections X and XI the conclusion and the future scope.

Related Work

Crowl and Louvar [1] and Mannan [2] give the standard treatments of flammability, lower and upper explosive limits and the layered safeguards used in process plant. Both make the point developed in Section V-B, that a detector's value derives from its calibrated sensitivity and bounded response time, not from its presence.

On sensing technology, Wang and colleagues [3] review metal-oxide gas sensors and document their two structural weaknesses: broad cross-sensitivity, so that the same response can arise from several gases, and a marked dependence of baseline and sensitivity on ambient humidity. Fine and colleagues [4] similarly report drift and the need for periodic recalibration. These findings bear directly on a channel read at 82 % relative humidity without calibration. For installation requirements, the IEC 60079 series [5] sets out explosion-protection concepts for equipment in hazardous areas and, in its gas-detector parts, the performance requirements including response time and calibration. The ESP8266 platform [6] and the Blynk framework [7] supply the compute and dashboard layers.

Table 1. Representative Related Work and its Relation to This Study

Ref.	Year	Focus and scope	Method and validation	Relation to this work
[1]	2011	Chemical process safety fundamentals	Standard textbook treatment	Source of LEL and layered-safeguard framing
[2]	2012	Loss prevention in process industries	Reference compendium	Requirements a detector must meet
[3]	2010	Metal-oxide gas sensing	Review of mechanism and response	Humidity and cross-sensitivity limits
[4]	2010	Metal-oxide sensor drift and calibration	Review; field experience	Establishes the recalibration need
[5]	2016-2025	Explosive atmospheres; gas detector performance	International standard series	Certification and response-time gap
[6]	—	ESP8266 platform	Vendor documentation	Compute and Wi-Fi stage
[7]	—	Blynk IoT platform	Vendor documentation	Dashboard and notification transport

The reference numbering has been corrected in this revision. An earlier draft cited the ESP8266 and Blynk documentation as [6] and [7] in the text while the reference list placed an unrelated power-systems paper at [6], so every citation from that point onward disagreed with the list by one position. That paper now appears at [8] and the numbering is consistent.

1. The Standard Has Moved

One point of currency is worth recording, since the whole of Section VII rests on it. IEC 60079-29-1, which specified performance requirements for detectors of flammable gases and which earlier drafts of this work cited directly, has been replaced by IEC 60079-29-0:2025, covering general requirements, test methods and acceptance criteria for flammable, oxygen and toxic gas detection equipment. Two further parts of the same series bear on the present discussion: Part 29-2 addresses selection, installation, use and maintenance of detectors for flammable gases, and Part 29-3 gives guidance on the functional safety of fixed gas detection systems. That last part is directly relevant to the scope note in Section VI-B, since an automated shutdown driven by a gas detector is a functional-safety matter and not merely a wiring one.

2. Reference Values for the Alarm Bands

Because Sections III-A and V-C turn on what a calibrated instrument would have to measure, it is useful to fix the explosive limits of the gases such a node might encounter. Table 2 collects published values together with the absolute concentrations that the conventional alarm fractions correspond to. None is a measurement of this prototype.

Table 2. Published Lower Explosive Limits and the Absolute Alarm Bands They Imply

Gas	LEL (% v/v)	100 % LEL (ppm)	20 % LEL (ppm)	60 % LEL (ppm)
Methane	5.0	50,000	10,000	30,000
Propane	2.1	21,000	4,200	12,600
Hydrogen	4.0	40,000	8,000	24,000
Hexane	1.1	11,000	2,200	6,600

Explosive limits are published values from gas-detection reference sources. The ppm columns are computed from them by Eqs. (1) and (7). The 20 % and 60 % fractions are common industry practice for low and high alarms, quoted here for orientation; they were not implemented or validated on this device. Note also that portable monitors are frequently set to alarm at 10 % of the limit, so the fractions themselves are a matter of site policy rather than physics.

Table 2 has a consequence that is easy to miss when alarm levels are discussed only as percentages. A detector intended to alarm on methane at 20 % of the explosive limit must resolve 10,000 ppm and must remain accurate up to 30,000 ppm at the high alarm. These are large concentrations, far above the parts-per-million range in which low-cost air-quality sensing is usually discussed. The detection range of the module used in this prototype is not documented in the record, so whether it even spans the band in Table 2 is unknown. That is a separate deficiency from the absence of calibration, and it would remain even if a calibration were performed.

Governing Relations

1. Concentration and the Explosive Limit

A combustible gas burns only within a concentration band bounded below by the lower explosive limit. Detector alarms are conventionally set as fractions of that limit,

$$C_{\%LEL} = \frac{C}{LEL} \times 100\% \tag{1}$$

with a low alarm typically near 20 % of the limit and a high alarm near 60 %, so that action is taken well below a flammable mixture. Concentrations expressed by volume convert to parts per million as

$$C_{ppm} = 10^4 \times C_{\%v/v} \tag{7}$$

Fig. 1 shows the resulting bands for four common gases. Evaluating Eq. (1) requires C in absolute units, which requires calibration.

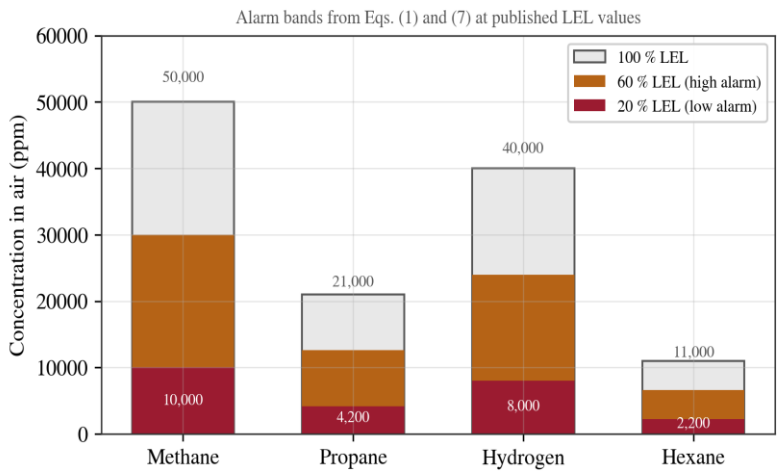

Figure 1: Alarm bands as absolute concentrations for four gases, computed from published explosive limits by Eqs. (1) and (7). The prototype's gas channel is not calibrated to this axis and cannot be placed on it.

2. Metal-Oxide Sensor Response

A metal-oxide sensing element does not output concentration. It outputs a resistance whose ratio to a baseline follows an approximately power-law relation with concentration [3],

$$\frac{R_s}{R_0} = A\,C^{-\alpha} \tag{2}$$

where A and α are gas-specific and R_0 is the baseline in clean air. Both R_0 and the fitted constants shift with temperature and humidity, which is why Eq. (2) can only be inverted after calibration in the installed environment.

3. Response and Detection Time

Sensor response is characterised by T_{90}, the time to reach 90 % of the final reading after a step change in concentration. The safety-relevant quantity is the total detection-to-alarm time,

$$\tau_{det} = T_{90} + t_{proc} + t_{comm} \tag{3}$$

comprising sensor response, processing and communication delay. Standards place explicit bounds on this quantity; it is not an incidental performance figure.

4. Ventilation

For a relay-driven extraction fan serving a volume V_r, the air-change rate is

$$n = \frac{3600\,Q_v}{V_r} \quad [\mathrm{h}^{-1}] \tag{4}$$

and the decay of a passive contaminant under perfect mixing is

$$C(t) = C_0 e^{-nt} \tag{5}$$

from which the time to dilute from an initial concentration to a target follows as

$$t_{dil} = \frac{1}{n}\ln\frac{C_0}{C} \tag{6}$$

Equations (4) to (6) determine whether an actuator achieves anything useful. Neither Q_v nor V_r was documented for this prototype, but the relations can still be evaluated for representative values, which is done in Section V-E.

Prototype and Methodology

1. Architecture

Fig. 2 shows the node. A metal-oxide combustible-gas sensor, a flame sensor read through the analogue input, and a temperature and humidity sensor feed an ESP8266 controller. The controller drives a buzzer and a relay-switched extraction fan and publishes all channels to a cloud dashboard, which also issues notifications. Every block in the upper part of the figure was built. The three items shown as absent at the foot of it are the qualification steps on which the whole of Section V turns.

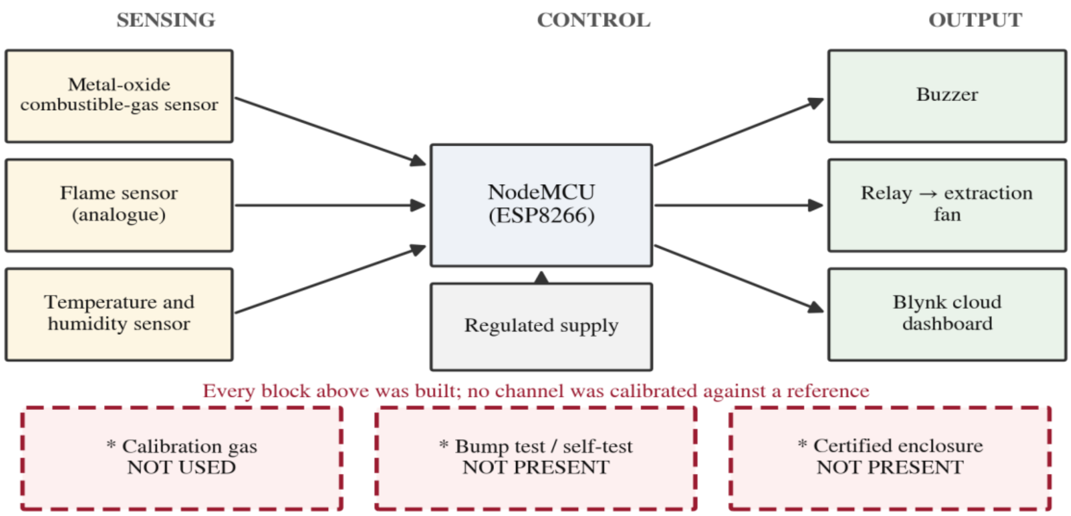

Figure 2: Prototype architecture. Every block was built; no channel was calibrated against a reference gas or a reference thermometer.

2. Apparatus

Table 3 lists the apparatus as documented. Ratings are given only where the source material states them.

Table 3. Apparatus Used in the Prototype

Item	Type / rating	Quantity
Controller board	NodeMCU (ESP8266)	1
Combustible-gas sensor	Metal-oxide, analogue out; part number and range not stated	1
Flame sensor	Analogue, mapped in firmware	1
Temperature-humidity sensor	Digital, single-wire	1

Relay module	Rating not stated in the record	1
Extraction fan	DC; flow rate not stated in the record	1
Buzzer	Rating not stated in the record	1
Regulated power supply	Transformer, bridge, regulator	1
Dashboard	Blynk (cloud)	1

The gas module's part number and stated detection range are not recorded, and neither is the fan's flow rate or the enclosure volume. The first omission is why Section II-B cannot say whether the sensor spans the alarm band; the second is why Section V-E must use assumed values.

3. Procedure

1. Assemble the sensing, control and actuation stages on the regulated supply and flash the firmware from the Arduino IDE.
2. Read the flame sensor on the analogue input and map its range in firmware to discrete proximity states.
3. Bring the node online and record the displayed channel values.
4. Present a flame stimulus and confirm that the notification is issued.

Results and Discussion

1. Recorded Telemetry

Table 4 reports what was captured. All values belong to a single instant. Fig. 3 shows the same three channels as a fraction of dashboard full scale.

Table 4. Recorded Dashboard Telemetry (Single Snapshot)

Channel	Value	Status
Temperature	32 degrees Celsius (full scale 0 to 100)	measured, uncalibrated
Relative humidity	82 % (full scale 0 to 100)	measured, uncalibrated
Gas level	0 (full scale 0 to 100)	raw channel; no response observed
Flame notification	issued and delivered	observed

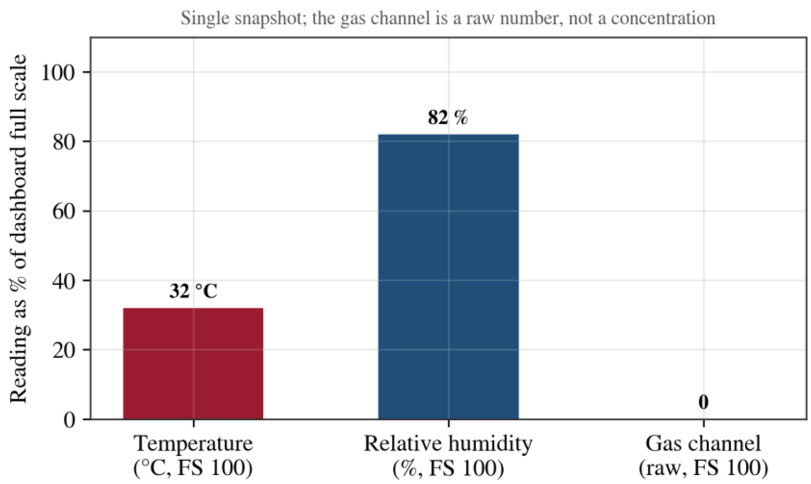

Figure 3: The recorded snapshot. The gas channel is a raw dashboard number, not a concentration, and the plot contains one sample per channel.

2. Why No Concentration Is Reported

The gas channel reads zero. Three statements follow, and the distinction between them is the substance of this section.

What the reading establishes. It establishes that the sensing element produced no significant response relative to its baseline at that instant.

What it does not establish. It does not establish that combustible gas was absent, because the element's minimum detectable concentration was never determined; it does not establish that the sensor was working, because no positive-response test against a known stimulus was recorded; and it does not establish a concentration in ppm or per cent of the explosive limit, because Eq. (2) was never inverted with calibrated constants. A zero on an unvalidated channel and a zero on a calibrated instrument look identical and mean entirely different things.

What cannot be reported at all. Without calibration gas there is no C, hence no value from Eq. (1) and therefore no defensible alarm threshold; without a step-change trial there is no T_{90} and hence no τ_{det} from Eq. (3); and without repeated exposures there is no detection or false-alarm probability. None of these quantities is estimated here.

3. What a Calibrated Instrument Would Have to Span

Table II makes the requirement concrete in a way that percentages alone do not. To alarm on methane at the conventional low threshold, an instrument must resolve 10,000 ppm and remain accurate to 30,000 ppm; for propane the corresponding figures are 4,200 and 12,600 ppm. These are the numbers a calibration would have to establish and a datasheet would have to cover. Because the module's stated range is not recorded, this prototype cannot be checked against them even in principle, and no future calibration can succeed if the element saturates below the low alarm. Confirming the module's range is therefore a prerequisite to calibration rather than a step that follows it.

4. The Humidity Reading Is Not Incidental

The recorded relative humidity of 82 % is directly relevant to the gas channel rather than merely descriptive. Metal-oxide elements exhibit humidity-dependent baseline resistance and sensitivity, and the dependence is strongest at high humidity [3]. A baseline established in dry laboratory air therefore does not transfer to an 82 % environment, and an uncompensated channel may read low, high or simply differently. Any future calibration must be performed across the humidity range of the intended installation, not at a single condition.

5. What the Ventilation Actuator Can Achieve

The relay drives an extraction fan, and the record treats this as the protective response. Equations (4) to (6) allow the claim to be examined even though neither the flow rate nor the enclosure volume was documented. Taking an enclosure of 50 m^3, which is a small process room and is an assumption rather than a measurement, Table 5 gives the air-change rate and dilution times for three plausible fan flows. Fig. 4 plots the decay.

Table 5. Air-Change Rate and Dilution Time for an Assumed 50 m^3 Enclosure (Computed, Not Measured)

Fan flow Q_v	Air-change rate n	Time to halve	Time to reach 10 %
0.02 m^3/s	1.44 per hour	28.9 min	95.9 min
0.05 m^3/s	3.60 per hour	11.6 min	38.4 min
0.10 m^3/s	7.20 per hour	5.8 min	19.2 min

Computed from Eqs. (4) and (6) for an assumed enclosure volume of 50 m^3 and perfect mixing. Neither the fan flow nor the enclosure volume was documented for this prototype, and perfect mixing is an idealisation that real enclosures do not achieve, so these times are optimistic. The table describes a class of arrangement, not this device.

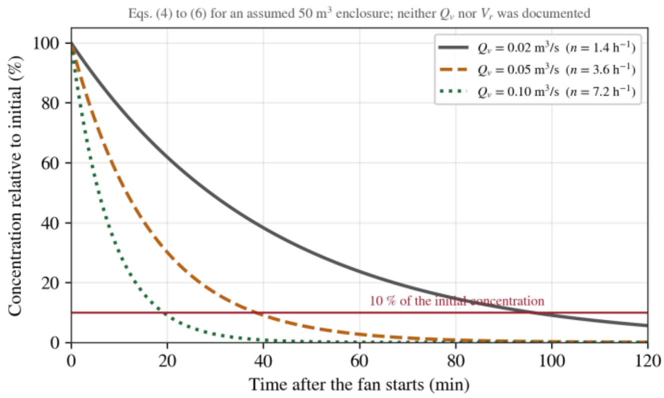

Figure 4: Dilution of a passive contaminant under Eqs. (4) to (6) for three fan flows in an assumed 50 m^3 enclosure.

The reading is unambiguous and it matters. Even a comparatively vigorous fan takes several minutes to halve a concentration and tens of minutes to reduce it by an order of magnitude. Ignition of a flammable mixture, by contrast, occurs in milliseconds once an ignition source is present. Ventilation is therefore a slow mitigation that reduces the duration of a hazardous condition; it is not a protective response that prevents ignition during one. Describing a relay-driven fan as the safety response to a gas alarm overstates what it does, and the arithmetic rather than any judgement establishes this.

6. The Flame Channel

The flame sensor was read on the analogue input and its range mapped in firmware to proximity categories, and a fire-detected notification was demonstrably issued and delivered. This confirms the alerting path end to end, which is a genuine result. It does not establish detection distance, field of view, response time or immunity to sunlight and hot surfaces, none of which was tested. The mapping thresholds are firmware constants, not calibrated boundaries.

7. What the Data Supports

Table 6 separates the prototype's demonstrated capability from what remains unmeasured, and Fig. 5 shows the same division by safety-function layer.

Table 6. Measured, Built, Indeterminate and Unaddressed Quantities

Quantity or capability	Value	Status
Temperature reading	32 degrees Celsius	measured, uncalibrated
Humidity reading	82 %	measured, uncalibrated
Gas channel output	0 (raw)	measured, uncalibrated
Alert path end to end	functions	demonstrated
Actuator switching	functions	demonstrated
Alarm bands in absolute units	10,000 ppm at 20 % LEL, methane	computed, Eqs. (1) and (7)
Dilution time, assumed 50 m^3 and 0.05 m^3/s	38.4 min to 10 %	computed, Eq. (6)

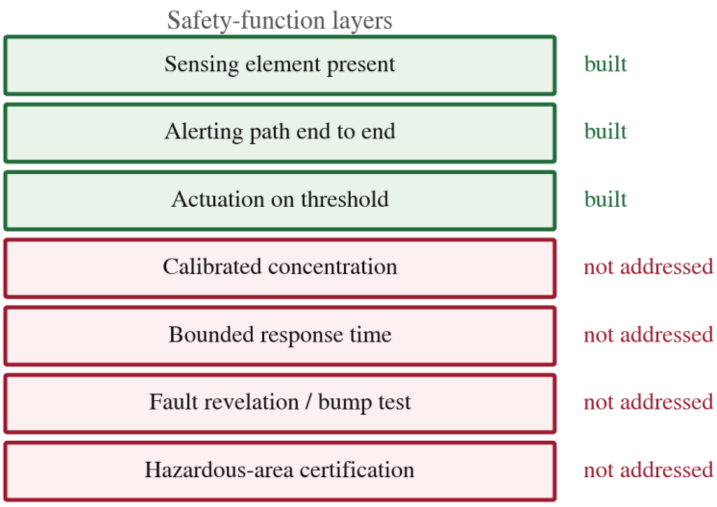

Figure 5: Safety-function layers. The sensing and alerting layers were built; the qualification layers were not addressed.

Discussion

The prototype establishes that a low-cost node can sense several environmental channels, apply threshold logic, actuate a relay and deliver a notification to a phone. That is a real result for the sensing and alerting chain. What it does not establish is that any of those channels measures anything, in the sense that a measurement is a number traceable to a reference. The distinction is the whole of this paper, and it is sharper here than in most instrumentation contexts because the consequence of a wrong reading is not an inaccurate report but an undetected flammable atmosphere.

1. Qualitative Position

Table 7 sets out the structural properties that can be asserted, each with the relation or source that supports it.

Table 7. Qualitative Properties of the Prototype and the Proposed Architecture

Feature	Property	Basis
Metal-oxide sensing	Low cost; cross-sensitive; humidity dependent	[3], [4]
Flame channel	Alert path demonstrated end to end	This work
Cloud dashboard	Remote visibility; depends on network coverage	This work

Relay ventilation	Actuates; dilutes on a timescale of minutes to tens of minutes	Eqs. (4) to (6)
Calibration	Converts a raw channel into a measurement	Eq. (2)
Bump testing	Distinguishes a true zero from a failed sensor	[5]
Module range	Must span the alarm band before calibration can succeed	Table II

2. Scope Note on the Source Design

The design documentation describes machine-learning anomaly detection trained on historical data, integration with SCADA for automated shutdown, predictive capability improving over time, and networked sensors across storage tanks, pipelines and processing units. The constructed node contains a single sensor set on one board, threshold logic in firmware, and a relay. No learning algorithm, no historical dataset, no SCADA interface and no distributed deployment exists. These are recorded as design intent and excluded from every claim here. The distinction is not pedantic: an automated shutdown driven by gas detection is a safety-instrumented function with its own integrity requirements, addressed in the functional-safety part of the detector standard series [5], and describing a prototype relay as though it performed one would materially misrepresent the work.

Certification and Availability Gap

Three requirements apply to equipment intended for a genuinely hazardous area, and are stated here because the prototype meets none of them.

Ignition source control. Electronic equipment mounted in a flammable atmosphere must not itself be an ignition source, which is the entire subject of the IEC 60079 protection concepts [5]. An open prototype board with a switching relay is an ignition source; a relay contact arc in a flammable mixture is precisely the hazard the installation exists to avoid. This is the most serious of the three, because it means the device could contribute to the event it is intended to detect.

Bounded response. Standards bound detector response time, because a detector that alarms late has not performed its function. Since τ_{det} was never measured, no such bound can be claimed. The ventilation analysis of Section V-E compounds this: even a prompt alarm is followed by a mitigation that takes tens of minutes.

Availability and fault detection. A safety function must reveal its own failure. Without bump testing, a broken sensor and a clean atmosphere are indistinguishable on this node, and the dashboard will display a reassuring zero in both cases.

The prototype is therefore best understood as a teaching and development platform for the sensing and alerting chain, and this paper makes no claim of suitability for installation in a hazardous area.

Limitations

The following limitations bound every claim made in this paper.

- The dataset is one sample on three channels at one instant. No statistical quantity of any kind can be derived from it.
- No channel was calibrated against any reference. The temperature and humidity readings are uncalibrated, and the gas channel is a raw ratiometric number that cannot be converted to a concentration.
- The zero on the gas channel establishes the absence of a response, not the absence of gas and not a working sensor. No positive-response test was performed at any point.
- Detection time, minimum detectable concentration, cross-sensitivity, warm-up behaviour, drift, and detection and false-alarm probability were not measured, and none is estimated.
- The gas module's part number and stated detection range are not recorded, so it cannot be established whether the element spans the alarm bands of Table II.
- The alarm fractions of 20 % and 60 % are common industry practice quoted for orientation. They are a matter of site policy, they were not implemented on this device, and portable instruments are frequently set lower.
- The ventilation figures of Table V and Fig. 4 use an assumed enclosure volume and assumed fan flows, with perfect mixing. Neither quantity was documented, and real enclosures mix imperfectly, so the times given are optimistic.
- The flame channel's detection distance, field of view, response time and immunity to sunlight and hot surfaces were not tested.

- The machine-learning, SCADA and distributed-deployment features named in the source design documentation were not built and are excluded from every claim.
- No aspect of hazardous-area certification was addressed, and no claim of suitability for installation in a classified area is made anywhere in this paper.

Proposed Architecture and Qualification Plan
Fig. 6 shows the architecture the measurements motivate. The additions are qualification steps rather than features: a calibration path, a positive self-test, and logging with a time base.

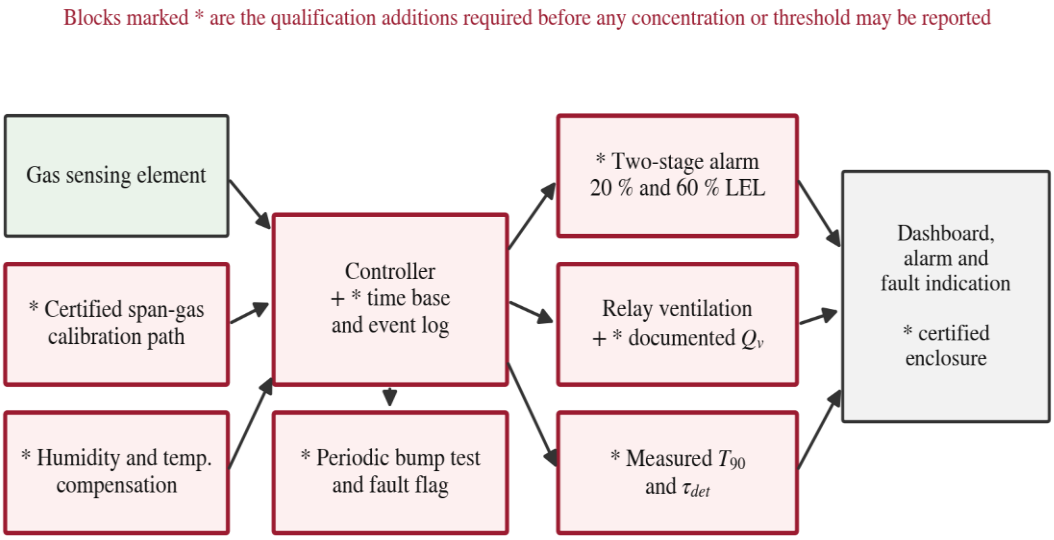

Figure. 6: Proposed architecture. Blocks marked with an asterisk are the qualification additions required before any concentration or threshold may be reported.

1. Calibration and Compensation
Exposure to certified span gas at two or more concentrations, repeated across the humidity range of the installation, fixes the constants of Eq. (2) and makes Eq. (1) evaluable. The concentrations chosen must bracket the alarm band of Table II for the target gas, which is why confirming the module's range comes first. Periodic bump testing, a brief exposure confirming a positive response, then distinguishes a genuine zero from a failed sensor, which is the single most valuable addition to the present design.

2. Two-Stage Alarming and Ventilation
With concentration available, low and high alarms can be set at defensible fractions of the explosive limit rather than at arbitrary firmware constants, and the extraction fan can be commanded at the low alarm with its effect verified through Eqs. (4) to (6) using a documented flow rate and enclosure volume. Section V-E indicates what such verification will show: the fan buys time, and the design should be presented on that basis.

3. Qualification Plan
Table 8 sets out the steps that would convert the demonstration into an instrument, and Table 9 gives the context values that are standard practice or literature rather than measurements of this device.

Table 8. Qualification Plan Required Before Any Reading Can Be Reported

Step	Method	What it yields
Confirm the module range	Datasheet capture for the fitted element	Whether the sensor spans the band of Table II
Calibrate against certified gas	Two or more known concentrations bracketing the alarm band	Constants of Eq. (2); makes Eq. (1) evaluable
Compensate for humidity and temperature	Repeat calibration across the installation's range	A baseline valid at the recorded 82 % RH
Measure response time	Step change in concentration with a time base	T_{90}, and τ_{det} through Eq. (3)

Add bump testing and fault revelation	Periodic positive-response check and a distinct fault flag	Makes a zero reading meaningful
Characterise the flame channel	Distance, angle and interference trials	Detection distance, field of view and immunity
Document the ventilation stage	Fan flow rate and enclosure volume	Evaluates Eqs. (4) to (6) for the real installation
Address certification	Appropriately protected equipment for the area classification	Removes the ignition-source objection of Section VII

Table 9. Illustrative Figures (Standards and Literature, Not Results)

Item	Illustrative value	Status
Typical low alarm	About 20 % LEL	common practice [1]
Typical high alarm	About 60 % LEL	common practice [1]
Lower explosive limit, methane	5.0 % v/v	published value, Table II
Metal-oxide humidity sensitivity	Largest at high relative humidity	literature [3]
Dilution time, assumed enclosure	Tens of minutes	computed, Eq. (6)

Alarm fractions are common industry practice quoted for orientation. They were not implemented or validated on this device, and the explosive limits are published reference values rather than measurements made here.

Conclusion

An IoT node combining metal-oxide gas sensing, flame sensing, temperature and humidity measurement, relay-driven ventilation and cloud alerting was built and exercised. The recorded telemetry was a single snapshot of 32 degrees Celsius, 82 % relative humidity and a gas channel reading zero, together with a demonstrated fire-detected notification which confirmed the alerting path end to end.

The assessment then established what such a record can support. Because the gas element was never exposed to certified calibration gas, its output remains an uncalibrated ratiometric number: no concentration can be reported, no alarm threshold can be justified, and the zero reading establishes only the absence of a response, not the absence of gas and not a working sensor. Detection time, minimum detectable concentration, cross-sensitivity and drift were likewise not measured, and none was estimated. The recorded 82 % humidity was identified as directly consequential rather than incidental, since metal-oxide response depends most strongly on humidity in exactly that region.

This revision added two quantitative elements. The alarm bands were expressed in absolute units from published explosive limits, showing that a methane low alarm at 20 % of the limit requires an instrument to resolve 10,000 ppm and remain accurate to 30,000 ppm at the high alarm; since the fitted module's range is not documented, it cannot be established that calibration would even be possible. And the ventilation relations were evaluated, showing that a fan serving an assumed 50 m^3 enclosure halves a concentration in 6 to 29 min and reduces it tenfold in 19 to 96 min depending on flow. Ventilation is therefore a slow mitigation rather than a protective response, and the design should be described on that basis.

The certification, bounded-response and fault-revelation requirements that a hazardous-area installation imposes were stated explicitly along with the prototype's distance from them, including the observation that an unprotected board with a switching relay is itself an ignition source. A qualification path was specified in which range confirmation, calibration, humidity compensation and periodic bump testing convert a functioning demonstration into an instrument whose readings mean something. No claim of suitability for installation in a hazardous area is made.

Future Work

Several extensions follow directly from the limitations above.

- Confirm the sensing element's range-Record the fitted module's part number and stated detection range, and check it against the alarm bands of Table 2 before any calibration is attempted.
- Calibrate against certified gas-Expose the element to known concentrations of the target gas, bracketing the alarm band, to fix Eq. (2) and make reporting in per cent of the explosive limit possible.
- Compensate for humidity and temperature-Repeat calibration across the installation's humidity range, given

the 82 % relative humidity recorded here.

- Measure response time-Apply step changes and record T_{90}, t_{proc} and t_{comm} so that τ_{det} in Eq. (3) becomes a result.
- Add bump testing and fault revelation-Implement a periodic positive-response check and a distinct fault indication, so that a zero reading is meaningful.
- Characterise the flame channel-Measure detection distance, field of view and immunity to sunlight and hot surfaces.
- Document the ventilation stage-Record fan flow and enclosure volume so that Eqs. (4) to (6) can be evaluated for the actual installation rather than an assumed one.
- Address certification before any field use-Any deployment in a classified area requires appropriately protected equipment; the present open board with a switching relay is not suitable.

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