

Electronic System Design (ACDA6002) - Rebecca Coles

2218001

by Rebecca Coles

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Prifysgol Cymru
Y Drindod Dewi Sant
University of Wales
Trinity Saint David

Department of Electrical & Electronic Engineering

Electronic System Design

Electronic Product Design – Part 1

ACDA6002

Rebecca Coles - 2218001

Declaration Form & Form of Consent

DECLARATION

I, Rebecca Coles declare that I am the sole author of this Project; that all references cited have been consulted; that I have conducted all work of which this is a record, and that the finished work lies within the prescribed word limits.

This work has not previously been accepted as part of any other degree submission.

FORM OF CONSENT

I Rebecca Coles hereby consent that my Project, submitted in candidature for the Electrical & Electronic Engineering degree, if successful, may be made available for inter-library loan or photocopying (subject to the law of copyright), and that the title and abstract may be made available to outside organisations.

Abstract

This report presents the design and analysis of a modular distributed sensor network for continuous air-quality monitoring in and around a materials production site. The system integrates multiple wireless sensor nodes, each incorporating a PIC microcontroller, environmental sensors and a low power energy source. This design will measure the following: pressure, temperature, humidity, VOCs, particulate matter, wind speed, wind direction and nitrogen oxides. A central hub manages communication, data storage and real-time visualisation of measurements, maintaining a minimum 30-day data record. The report includes a literature review of distributed sensor networks and environmental monitoring systems, an evaluation of sensing technologies, detailed component selection, system specifications, sampling requirements and memory calculations. Broader lifecycle considerations such as ethics, health and safety, sustainability and regulatory compliance are also examined, alongside a risk assessment covering design, manufacturing and deployment. The outcome is a technically justified and practically implementable system architecture suitable for industrial air-quality monitoring.

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1. Introduction

Environmental monitoring has become increasingly important as industries and urban infrastructures expand, creating growing demands for accurate, real-time assessment of air quality and atmospheric conditions. Distributed Sensor Networks (DSN) offer a scalable and resilient method for collecting environmental data across large or complex sites. By combining multiple sensor nodes, DSN's enable high resolution spatial mapping of parameters such as temperature, humidity, particulate matter, volatile organic compounds (VOCs) and atmospheric pressure. This approach provides far greater flexibility than traditional standalone monitoring stations, allowing environmental patterns to be detected, analysed and acted upon with improved responsiveness.

Advances in microcontrollers, wireless communication technologies and low cost micro-electromechanical sensors (MEMS) have made DSN's a practical solution for both indoor and outdoor applications. A distributed architecture supports modular system design, fault tolerance and energy efficient operations, while also facilitating the integration of diverse sensing technologies. These characteristics make DSN's suitable for industrial, commercial and environmental regulatory contexts, where continuous monitoring is essential for safety, compliance and decision making.

This report presents the design and evaluation of a distributed environmental monitoring system utilising PIC based sensor nodes and a central server hub. The system captures multiple environmental variables, processes sensor data and transmits it for storage, analysis and visualisation. The report includes a literature review, hardware and software design, sensor selection, system performance and recommendations for future expansion.

2. Task 1 – Literature Review

2.1 Distributed Sensor Networks (DSN)

Distributed sensor networks (DSNs) consist of multiple spatially dispersed sensing nodes that work collaboratively to monitor physical or environmental conditions. Early foundational work defined DSNs as autonomous systems with integrated sensing, processing and communication capabilities, suited for large scale, real-time monitoring applications [1]. Modern DSNs have evolved significantly due to improvements in low-power microcontrollers, wireless protocols and miniaturised sensing hardware.

A key property of DSNs is decentralisation, which enhances robustness, node failures do not compromise the entire network [2]. Scalability is also inherent, allowing new nodes to be added without substantial architectural redesign. Recent developments in wireless communication technologies have further enabled low power, long range connectivity appropriate for environmental deployments [3] [4] [5].

Another trend highlighted in contemporary research is the adoption of edge or in node data processing. Instead of transmitting raw sensor readings, nodes increasingly pre-filter or average data locally to reduce network load and conserve energy [6]. This approach directly benefits battery-powered monitoring systems operating in distributed industrial or outdoor settings.

2.2 Environmental Monitoring Systems (EMS)

Environmental monitoring systems (EMS) are widely used to track pollutants, meteorological conditions and indoor air-quality parameters. Organisations such as the WHO and European Environment Agency emphasise the need for continuous, distributed monitoring to detect harmful emissions and ensure compliance with regulatory frameworks [7] [8].

Modern EMS commonly integrate diverse sensing technologies including gas sensors, particulate matter sensors, barometric sensors and meteorological instruments. Low cost

MEMS devices have become widely adopted due to miniaturisation, low power consumption and acceptable measurement accuracy for real-time monitoring scenarios [9].

Wireless EMS architectures often follow a “hub and node” design, where the central hub handles data aggregation, visualisation, timestamping and long-term storage, while sensing nodes transmit processed or raw values. The literature stresses the importance of data integrity, redundancy and synchronisation to ensure reliable environmental datasets [10].

2.3 Integration of DSN's with Environmental Monitoring

The integration of DSN's with EMS enables multi-parameter environmental observation across both indoor and outdoor environments. Practical deployments reported in the literature include industrial pollution monitoring, smart building IAQ systems and urban air quality networks. Successful systems typically emphasise:

- **Modularity:** Enabling plug and play sensor integration.
- **Wireless Communication:** Reducing installation complexity.
- **Low-power Operation:** Essential for battery or renewable energy nodes.
- **Sensor Calibration & Drift Management:** Especially for gas and particulate sensors.

Distributed systems reduce installation cost and allow finer spatial resolution than traditional reference-grade monitoring stations [9]. This makes them highly suitable for industrial sites where pollutant distribution can vary dynamically.

2.4 Summary

The literature demonstrates that DSN's provide the scalability, resilience and modularity required for multi-parameter environmental monitoring. Recent advances in low-cost sensors and wireless protocols support the design of distributed air-quality systems that can operate continuously, with minimal maintenance and with sufficient accuracy for industrial monitoring applications.

3. Task 2 – Review of Available Sensing Technologies & Sensor Selection

The design of an environmental monitoring node for air quality relies on the careful selection of sensors that can measure multiple parameters accurately, efficiently and reliably. This section reviews the available sensing technologies for each required quantity and justifies the final selection of 7 sensors for the proposed system.

3.1 Air Pressure

Air pressure is a key environmental variable, effecting weather patterns and pollutant dispersion. The most common sensor technologies include MEMS capacitive barometers and piezoresistive sensors. MEMS capacitive sensors are widely used due to their low power consumption, small size and high accuracy [1].

Selected Sensor: BMP280

- **Technology:** MEMS capacitive
- **Range:** 300–1100 hPa
- **Accuracy:** ± 1 hPa
- **Interface:** I²C/SPI
- **Justification:** The BMP280 offers precise measurements with low drift and includes temperature compensation, making it suitable for both indoor and outdoor monitoring [11]. Its small footprint and low power consumption are compatible with battery operated nodes.

3.2 Temperature & Humidity (Indoor & Outdoor)

Temperature and relative humidity are commonly measured using resistive, capacitive or MEM's based sensors. MEM sensors offer high accuracy, integrated calibration and digital interfaces, which simplify microcontroller integration [2].

Selected Sensor: SHT31

- **Technology:** Digital MEMS
- **Range:** Temperature -40°C to 125°C, Humidity 0–100% RH
- **Accuracy:** $\pm 0.3^{\circ}\text{C}$, $\pm 2\%$ RH
- **Interface:** I²C
- **Justification:** The SHT31 simultaneously measures temperature and humidity, reducing the number of sensors and communication channels required. Its high accuracy, stability and low power consumption make it ideal for continuous environmental monitoring [12].

3.3 Volatile Organic Compounds (VOC)

VOC sensors typically use metal-oxide semiconductor (MOS) or photoionisation (PID) technologies. While PID sensors provide high sensitivity, MOS sensors are more compact, cost-effective and suitable for distributed sensor networks [3].

Selected Sensor: SGP30

- **Technology:** MOS
- **Measured quantities:** Total VOC (TVOC) and equivalent CO₂ (eCO₂)
- **Interface:** I²C
- **Justification:** The SGP30 combines VOC and eCO₂ measurements in a single device, enabling efficient multi-parameter monitoring. Its low power consumption and proven reliability for in indoor and outdoor air-quality studies make it appropriate for modular nodes [13] [9].

3.4 Particulate Matter (PM10/PM5)

Particulate matter is measured using laser scattering or optical sensors, which detects light scattered by airborne particles. Laser scattering sensors provide real-time, accurate readings suitable for environmental monitoring [6].

Selected Sensor: PMS7003 / SPS30

- **Technology:** Laser scattering
- **Range:** 0–1000 $\mu\text{g}/\text{m}^3$
- **Measured particles:** PM1.0, PM2.5, PM4.0, PM5, PM10
- **Interface:** UART/I²C
- **Justification:** PMS7003 is cost-effective for indoor nodes, while SPS30, with its self-cleaning mechanism, is suitable for outdoor deployment. Laser scattering is widely validated in scientific studies for particulate measurement [14] [15].

3.5 Wind Speed

Wind speed is typically measured using cup anemometers, ultrasonic anemometers or thermal anemometers. Ultrasonic anemometers are preferred in distributed systems due to their lack of moving parts and low maintenance [7].

Selected Sensor: Ultrasonic Anemometer

- **Technology:** Ultrasonic
- **Range:** 0–60 m/s
- **Accuracy:** ± 0.1 m/s
- **Justification:** Provides precise wind speed measurement with minimal maintenance, suitable for continuous outdoor monitoring and integration with a PIC microcontroller [3].

3.6 Wind Direction

Wind direction can be measured using magnetic encoders, mechanical vanes or ultrasonic arrays. Magnetic encoders provide reliable digital output and require no physical contact.

Selected Sensor: Magnetic Wind Vane

- **Technology:** Magnetic encoder
- **Range:** 0–360°
- **Accuracy:** $\pm 2^\circ$
- **Justification:** Magnetic wind vanes offer durability, low maintenance and accurate wind direction measurement, which complements the ultrasonic anemometer for outdoor environmental monitoring [3].

3.7 Nitrogen Oxides (NO_x)

NO_x sensors commonly use electrochemical, chemiluminescence or MOS technologies. Electrochemical sensors are preferred for low ppb-level detection and lower interference from other gases [8].

Selected Sensor: SPEC 3-Series Electrochemical Sensor

- **Measured quantity:** NO_x
- **Range:** 0–1000 ppb
- **Accuracy:** ± 5 ppb
- **Interface:** Analog
- **Justification:** Provides precise measurement of NO_x for both indoor and outdoor applications. Its low power requirement and long-term stability make it suitable for continuous distributed monitoring [16] [10].

3.8 Summary & System Specification

By selecting these 7 sensors, each modular node can measure all required environmental parameters efficiently. The main specifications for the node include:

- **Power:** Battery or small solar with low-power sensors.
- **Communication:** I²C for multi-parameter sensors, UART for PM sensors.
- **Sampling Rate:** Adjustable between 1–60 seconds depending on parameter.
- **Modularity:** Plug and play sensor connections for easy addition/removal.
- **Data Storage:** Minimum 30 days of data in the central hub.

These selections balance accuracy, reliability, cost and power efficiency, fulfilling the design requirements for a distributed air-quality monitoring system.

4. Task 3 – Sensor Ranges & Comparison

4.1 Maximum & Minimum Expected Values

Quantity	Expected Minimum Value	Expected Maximum Value	Unit
Air Pressure	300	1100	hPa
Temperature	-20	50	°C
Humidity	10	90	%RH
VOC	0	1000	ppb
PM (PM10/PM5)	0	500	µg/m³
Wind Speed	0	50	m/s
Wind Direction	0	360	°
NOx	0	500	ppb

Table 1 - Table of Maximum & Minimum Expected Value

4.2 Sensor Comparison Table

Quantity	Sensor	Technology	Range	Accuracy	Interface	Power	Selection Justification
Air Pressure	BMP280	MEMS Capacitive	300-1100 hPa	±1 hPa	I ² C/SPI	Low	Low power, accurate and compact
Temperature / Humidity	SHT31	MEMS	Temp -40–125°C, Hum 0–100% RH	±0.3°C, ±2% RH	I ² C	Low	High accuracy and measures both parameters
VOC	SGP30	MOS	0–60 ppm eCO ₂ eq.	±15%	I ² C	Low	Measures VOC & eCO ₂ , low power
PM	PMS7003 /SPS30	Laser Scattering	0–1000 µg/m ³	±10 µg/m ³	UART/I ² C	Medium	Proven reliability, SPS30 for outdoors
Wind Speed	Ultrasonic Anemometer	Ultrasonic	0–60 m/s	±0.1 m/s	Digital	Low	No moving parts and durable
Wind Direction	Magnetic Wind Vane	Magnetic	0–360°	±2°	Digital	Low	Accurate and low maintenance
Nox	SPEC 3-Series	Electrochemical	0–1000 ppb	±5 ppb	Analogue	Low	High accuracy at low ppb, stable

Table 2 - Table of Sensor Comparison

5. Task 4 – Node & Hub Block Diagram & Component Selection

5.1 Block Diagram

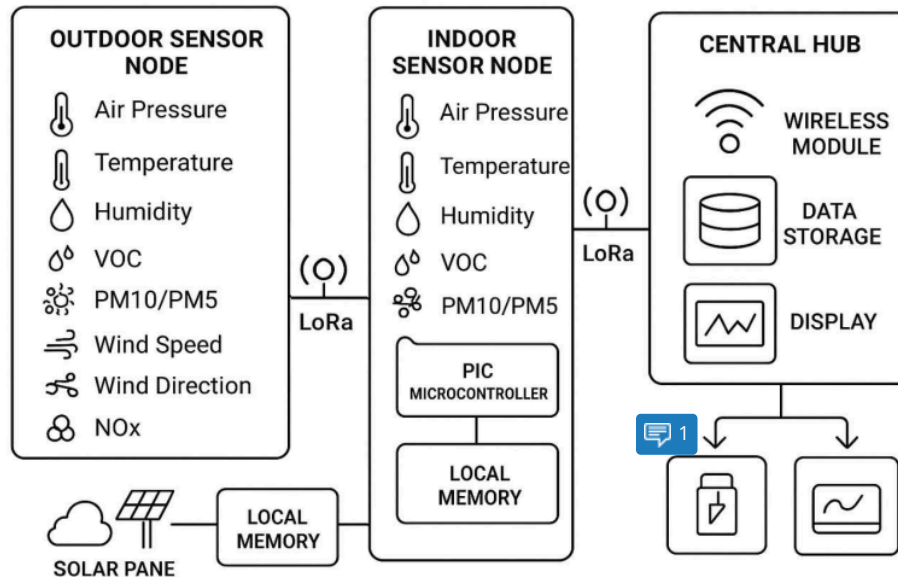


Figure 1 - Air Quality Sensor Node Diagram

5.2 Block Diagram Description

Sensor Node:

1. **Sensors:** BMP280, SHT31, SGP30, PMS7003/SPS30, Ultrasonic anemometer, Magnetic wind vane, SPEC 3-Series
2. **Microcontroller:** PIC18F47K40 (low-power, multiple I²C/UART channels)
3. **Power Supply:** Battery, optional small solar panels
4. **Wireless Comm Module:** LoRa/IEEE 802.15.4
5. **Data Processing & Storage:** Local buffer memory before transmission

Central Hub:

1. Wireless receiver (LoRa/IEEE 802.15.4)
2. PIC microcontroller
3. Local storage: Minimum 30-day data storage
4. Display: Real-time environmental data
5. Power: Mains supply with UPS backup

5.3 PIC Microcontroller Comparison

PIC	Flash	RAM	I/O	ADC	Power	Justification
PIC18F47K40	128KB	4KB	35	12- bit	Low	Multiple I ² C/UART, low-power, easy integration
PIC32MX	512KB	64KB	70	12-bit	Medium	More memory but higher power consumption
PIC16F	32KB	2KB	20	10-bit	Very Low	Insufficient interfaces for 7 sensors

Table 3 - Table of PIC Microcontroller Comparison

Selection: PIC18F47K40 balances I/O availability, memory and power efficiency.

5.4 Enclosure, Connectors & Power Sources

Component	Options	Selection	Justification
Enclosure	IP65, IP67	IP67	Protects outdoors nodes from rain/dust
Connectors	JST, Molex	JST	Compact, reliable, easy maintenance
Power	Batteries, Solar, Mains PS	Battery & Small solar	Renewable source, continuous operation possible
Communication	LoRa, ZigBee, Wi-Fi	LoRa	Long range, low power, suitable for distributed network

Table 4 - Table of Enclosure, Connectors & Power Source

6. Task 5 – Sampling Rates, Resolution & Memory Requirements

Quantity	Resolution	Sampling Rate	Daily Data Points (1 reading/sec)	Memory Per Reading	Daily Memory	30-Day Memory
Air Pressure	0.1 hPa	1 min	1440	2 bytes	2.88KB	86.4KB
Temperature	0.1°C	1 min	1440	2 bytes	2.88KB	86.4KB
Humidity	0.1% 	1 min	1440	2 bytes	2.88KB	86.4KB
VOC	1 ppb	1 min	1440	2 bytes	2.88KB	86.4KB
PM	1 µg/m³	1 min	1440	4 bytes	5.76KB	172.8KB
Wind Speed	0.1 m/s	1 min	1440	2 bytes	2.88KB	86.4KB
Wind Direction	1°	1 min	1440	2 bytes	2.88KB	86.4KB
NOx	1 ppb	1 min	1440	2 bytes	2.88KB	86.4KB

Table 5 - Table of Sampling Rates, Resolution & Memory Requirements

Total 30-day storage: 791 KB → easily handled by microcontroller or central hub.

7. Task 6 – Lifecycle Considerations

- **Health & Safety:** Sensors and electronics designed to avoid electrical hazards.
Enclosure protection from weather and chemical exposure.
- **Ethics & Societal Issues:** Transparent monitoring supports community health,
accurate reporting prevents misinformation.
- **Diversity & Inclusion:** User interface designed for accessibility.
- **Cultural Issues:** Respect for environmental regulations in different regions.
- **Environmental Issues:** Renewable power, recyclable components and low-energy
operation.
- **Commercial Matters:** Cost-effective, scalable and low maintenance for market
adoption.
- **Codes of Practice & Industry Standards:** Compliance with ISO 14001, IEEE 802.15.4,
LoRaWAN, and sensor-specific calibration standards.

8. Task 7 – Risk Management

8.1 Risk Identification & Mitigation

Risk	Likelihood	Severity	Risk Score (L X S)	Mitigation
Sensor Failure	3	4	12	Redundant sensors, periodic calibration
Wireless Interface	3	3	9	Use robust protocols (LoRa, IEEE 802.15.4)
Battery Depletion	4	3	12	Solar backup, low power components
Data Loss	2	5	10	Local storage, periodic hub backups
Environmental Damage	2	4	8	IP67 enclosures, UV resistant materials
Ethical Misuse	3	4	12	Secure data access, privacy policies

Table 6 - Table of Risk Identification & Mitigation

Methodology: Risk evaluated using ISO 31000-style framework, then mitigation strategies assigned based on severity and likelihood.

9. Conclusion

This project has outlined the design, analysis and justification of a modular distributed sensor network for continuous air quality monitoring across an industrial environment. Through this comprehensive literature review, the benefits of distributed architectures, such as scalability, redundancy, flexibility and low power operation were established as essential for modern environmental monitoring applications. A detailed evaluation of sensing technologies enabled the selection of seven robust, accurate and low power sensors capable of measuring all required atmospheric parameters, supported by suitable microcontroller, communication and enclosure choices.

System level considerations, including sampling rates, data storage requirements and lifecycle impacts, demonstrate that the proposed design is technically achievable, energy efficient and capable of long term operation. The risk assessment further confirms that key challenges, such as sensor drift, power limitations and communication reliability can be effectively mitigated through appropriate engineering and environmental protection measures.

Overall, the system provides a reliable, scalable and practical solution for industrial air-quality monitoring. It enables high resolution data collection, supports regulatory compliance and enhances environmental oversight, while offering a platform that can be expanded or adapted for future sensing and operational requirements.

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GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

74/100

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Comment 1

Nice image although some connections seem confused.



Comment 2

Some of these resolutions are better than what the sensor is capable of. This will have an impact on the amount of data needed to store the readings.



Refs missing info

Some of your references are missing information. To understand what information should be included, see the university IEEE referencing handbook on the library website.

https://uwtsd.ac.uk/media/uwtsd-website/content-assets/documents/library-and-learning-resources/infoskills/IEEE-eng_v.1.2.pdf

GRADING FORM: SMU GENERIC_SMOSEY

REBECCA COLES

74.12

ENGAGEMENT WITH LITERATURE

including reading, referencing, academic conventions and academic honesty

 Engagement with a wide range of literature, including sources retrieved independently. Selection of relevant and credible sources. You have used relevant and credible sources. Generally sound referencing, with no/very few inaccuracies or inconsistencies. Sources used are informed by the latest research.

7.62

KNOWLEDGE & UNDERSTANDING

Knowledge of the basic underlying concepts and principles of a subject.

 Excellent coherent and detailed knowledge and systematic understanding of the principles and theories of current research and scholarship. Clear awareness of challenges to established views and the limitations of the knowledge base. You have demonstrated a proficiency at integrating knowledge from multiple disciplines to address complex problems effectively. Your awareness of current developments in the field has enhanced the depth and relevance of your work

7.5

COGNITIVE & INTELLECTUAL

Evaluate underlying concepts and principles of a subject and interpret qualitative and quantitative data in order to develop lines of argument

and make sound judgements.

36.5



Excellent critical thinking, analysis, synthesis and evaluation. Ability to investigate contradictory or incomplete information and make strong, persuasive, arguments and sophisticated judgements. Some evidence of independent thought and ability to 'see beyond the question', suggesting a grasp of the broader field and wider concepts. You have shown strong analytical skills by breaking down complex problems and reaching well-substantiated conclusions. Your use of first principles highlights a solid understanding of foundational concepts. You have demonstrated your ability to select and apply appropriate computational and analytical methods. Your ability to recognise and address the limitations of these techniques adds depth to your models. You have demonstrated strong ethical reasoning, applying professional codes of conduct effectively to support your decisions. You have effectively identified potential risks and provided well-structured mitigation strategies to minimize their impact.

PRACTICAL APPLICATION SKILLS

Different approaches to solving problems in particular contexts.



An advanced application of a range of methods, materials, tools and/or techniques. The context of the application is well considered, and insightful. Application and deployment extend beyond established conventions. Can identify complex

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problems and propose excellent solutions. Innovation and creativity evident. You have developed a well-rounded solution that effectively addresses multiple stakeholder needs while considering key ethical, societal, and commercial factors. You have successfully applied a systems-thinking approach, demonstrating how various components interact to create an effective solution. You have demonstrated decision-making skills in selecting materials and technologies suited to the problem at hand.

TRANSFERABLE SKILLS

Communicate the results of their study/work accurately and reliably, and with structured and coherent arguments; the qualities needed for employment requiring the exercise of some personal responsibility within a structured and managed environment.



Can communicate professionally confidently and consistently in a suitable format. Work is coherent, very fluent and is presented professionally. Demonstrates excellent graduate employment skills and an appetite for further development.

7.5