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*by* Ellis Ashton

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## 1. Introduction

Distributed systems are commonly used in monitoring and control applications where functionality is divided across multiple nodes that operate and communicate to achieve a common system objective. As described by Tanenbaum and van Steen [1], such systems consist of independent computing elements that communicate over a network while presenting a full-system behaviour to the user. This architectural approach enables scalability, fault isolation, and modular expansion, making it well suited to environmental sensing applications.

The system presented uses a distributed architecture comprising a central control hub and a common design for each of the sensor nodes. Each sensor node is responsible for local data acquisition and preliminary processing, while the control hub aggregates measurements, manages communications, and provides user interaction. This separation of responsibilities aligns with established distributed system design principles discussed by Coulouris et al. [2], in which functional partitioning is used to reduce complexity and improve system maintainability.

Wireless communication is used to connect the distributed nodes, allowing flexible physical placement and reducing installation constraints. Star network topologies are widely used in wireless sensor networks due to its simplicity and ease of management, particularly when data rates are low and nodes operate intermittently [3]. In this design, sensor nodes communicate directly with the control hub, which acts as the coordination component within the system.

The overall aim of the project is to design and evaluate a practical distributed sensing system suitable for environmental monitoring. To complete this, realistic hardware implementation, manufacturable PCB design and reliable embedded software will be used to complete the design.

## 2. Schematic Design

The system is structured as a distributed architecture consisting of a control hub and common-design sensor nodes, each performing a clearly defined role within the overall system. Distributed system theory emphasises the importance of assigning well-bounded responsibilities to individual nodes to simplify coordination and improve fault tolerance, as outlined by Coulouris et al. [2]. In this design, sensor nodes focus exclusively on data acquisition and local processing, while the control hub is responsible for data aggregation, user interaction, and system management.

Communication between nodes is achieved using a wireless star topology, with the control hub acting as the central coordinator. This topology is commonly adopted in wireless sensor networks due to its straightforward addressing model and reduced communication overhead, particularly when compared with mesh or peer-to-peer architectures [3]. By centralising coordination at the hub, sensor nodes can operate with minimal firmware complexity and reduced power consumption.

At the protocol level, the system follows a layered communication approach in which application-level sensor data is transmitted over a wireless transport mechanism. The separation of functionality across conceptual layers mirrors the principles of the OSI reference model described by Zimmermann [6], enabling clearer system organisation and simplifying future expansion or modification of the communication stack.

The control hub maintains a persistent network connection and manages communication scheduling, ensuring that sensor nodes can transmit measurements reliably without clashing. This design choice reflects established best practice in distributed monitoring systems, where a central coordinator simplifies synchronisation and error handling while reducing the computational burden on the nodes [1].



## 2.1 Sensor node PCB

The sensor node schematic below shows the components and connector points for each sensor. This allows for the design to be common across all sensor applications whilst allowing for a modular design for any potential future expansion.

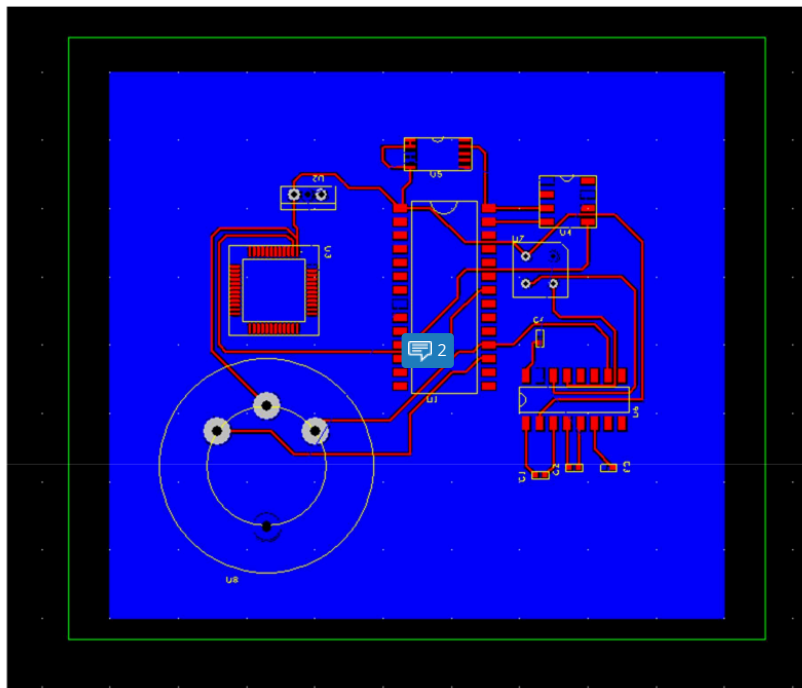


Figure 1 Sensor node PCB

## 2.2 Control hub PCB

The control hub design below, shows the control hub microcontroller and display connectivity, including a chip that allows transmission of data to and from the sensor node via a WIFI connection.

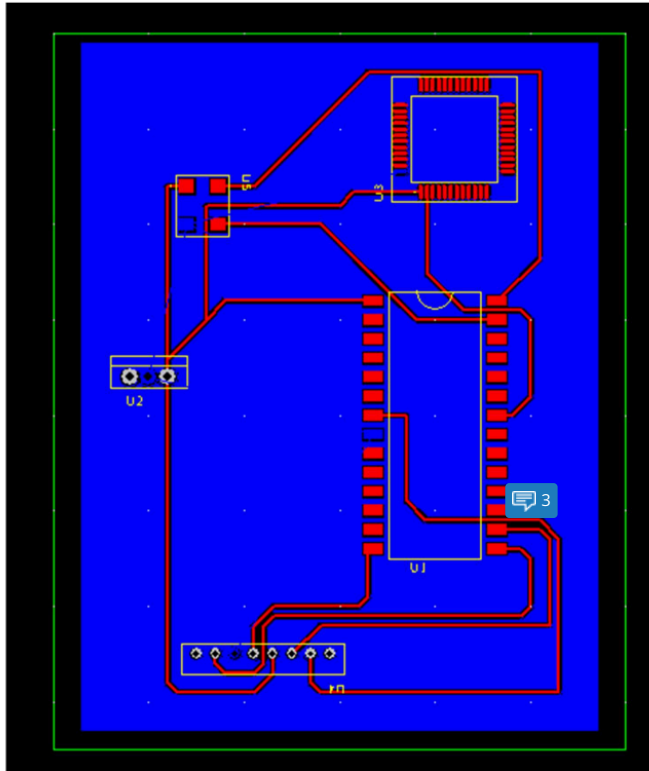


Figure 2 Control Hub PCB

## 2.3 Layer stack preview

The layer stack preview below illustrates the PCB layer technology used, including copper, silkscreen and through-hole interconnections which supports a dual-layer PCB structure

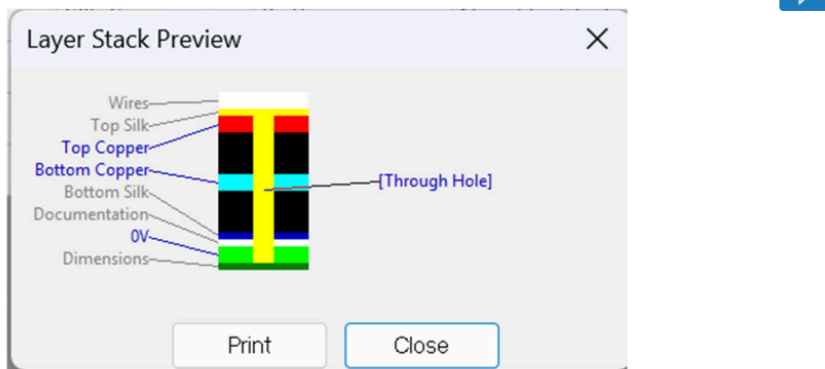


Figure 3 Layer stack preview

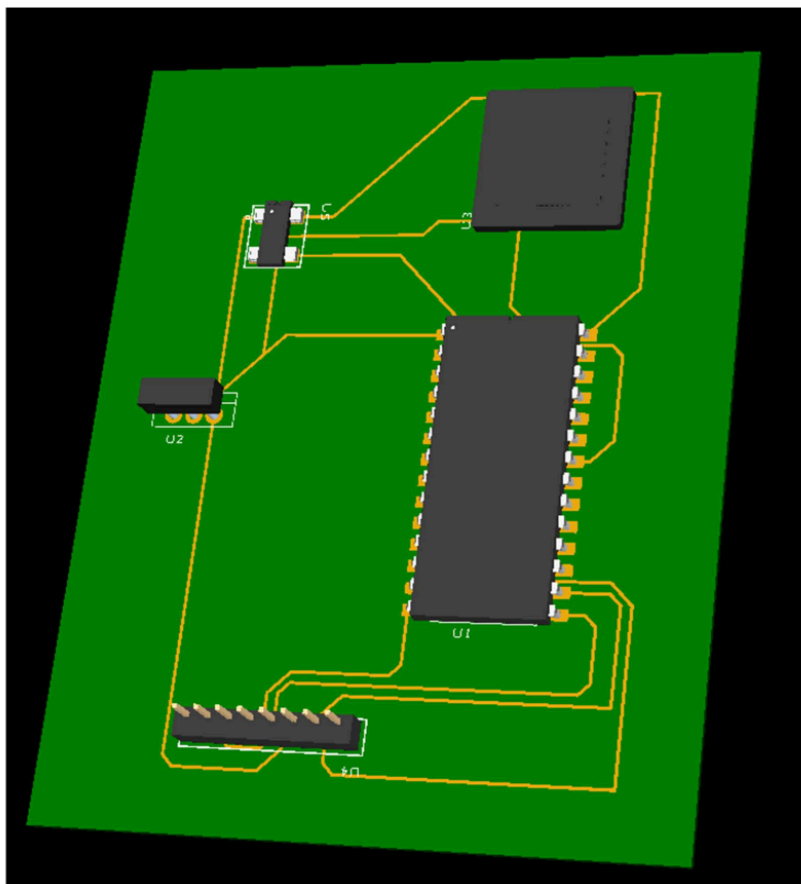


Figure 4 Control hub 3D view



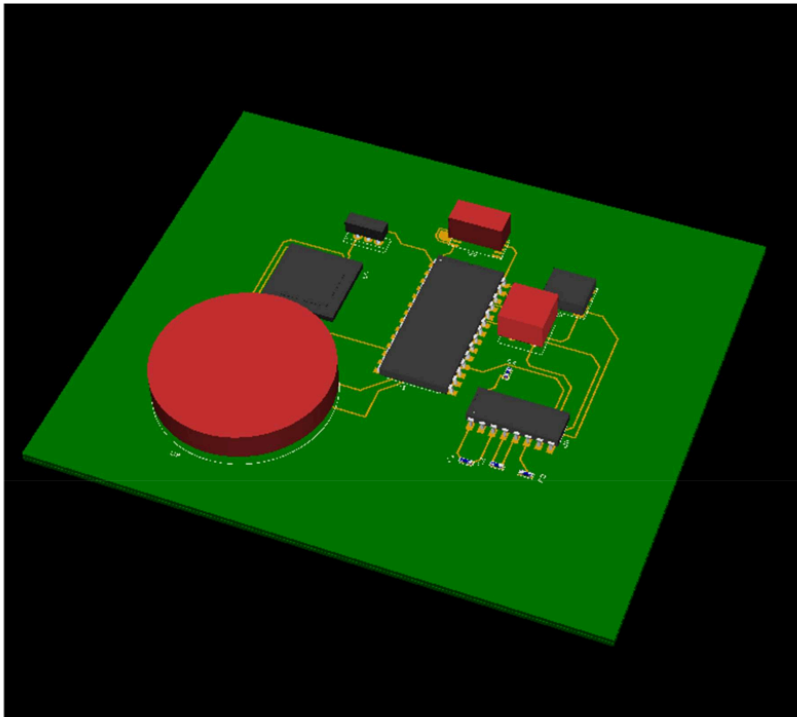


*Figure 5 Sensor node 3D view*

### 3. PCB Design

The hardware design of the distributed system is divided into two main elements, the control hub and the sensor node. This separation reflects the architectural decision to distribute sensing and processing tasks while maintaining a central point for coordination and user interaction. Such partitioning is commonly recommended in distributed monitoring systems to reduce node complexity and improve scalability [2]. EasyPC was used to create the PCB designs, The tool can be described as dated but had sufficient level of intuitivity to allow the designs to be accurate.

### 3.1 Control hub hardware

The control hub is built around the PIC18F4550 microcontroller, which was selected due to its integrated peripheral set, USB capability, and suitability for embedded control applications, as documented by Microchip Technology [5]. The microcontroller provides sufficient processing capability to manage communication scheduling, data aggregation, and interaction with peripheral devices such as displays or storage devices.

Wireless communication is provided by an ESP8266 Wi-Fi module, which integrates a complete TCP/IP stack and supports low-cost wireless connectivity [4]. By offloading network protocol handling to the ESP8266, the firmware running on the PIC microcontroller is simplified, reducing development complexity and improving reliability. This division of responsibilities between processing and communication hardware aligns with common practice in embedded wireless systems [1].

Power regulation and protection circuitry are incorporated to ensure stable operation of the control hub. The inclusion of reverse polarity protection and current limiting reflects good embedded hardware design practice, particularly for systems intended for unattended or long-term operation [12].

### 3.2 Sensor node hardware

The sensor node is designed to acquire environmental data locally and transmit measurements to the control hub. Environmental sensing is achieved using devices such as the BME288, which provides temperature, humidity, and pressure measurements with low power consumption, making it well suited to distributed sensor nodes [9]. For particulate matter monitoring, sensors including the PMS7003 and SPS30 were considered for the design, but disadvantages were identified between cost, accuracy, and long-term stability based on manufacturer specifications [10], [11].

Analogue and digital signal conditioning is implemented close to the sensors to minimise noise pickup and improve measurement reliability. Locating conditioning circuitry near the sensing elements follows established mixed-signal design guidance, which emphasises short signal paths and careful grounding to reduce interference [7].

The sensor node hardware is intentionally kept simple, with processing limited to sensor interfacing and data formatting prior to transmission. This design choice reduces power consumption and firmware complexity, consistent with recommended practices for wireless sensor networks [3].

## 4. Enclosure Design

Printed circuit board design plays an important part in the reliability and performance of mixed-signal embedded systems, particularly where analogue sensing and digital communication coexist. Poor layout practice can lead to increased noise coupling, electromagnetic interference, and reduced measurement accuracy. As discussed by Ott, careful consideration of grounding, routing, and component placement is essential to achieving robust system operation [7].

Both the control hub PCB and the sensor node PCB were designed using Easy-PC, with emphasis placed on ease of manufacture and ease of assembly. Through-hole components were selected where appropriate to improve mechanical robustness and simplify soldering, particularly for connectors and components subject to physical stress. Design-for-manufacture principles were applied throughout the layout process. This included aspects such as conservative track widths, adequate clearances, and standardised component footprints which is in line with established PCB manufacturing guidance [8].

Signal routing was organised to minimise coupling between sensitive analogue signals and high-frequency digital traces. Analogue sensor paths were kept as short as possible and routed away from digital communication lines, consistent with mixed-signal layout recommendations aimed at reducing electromagnetic interference [7]. Where possible, power and ground routing was arranged to provide low-impedance return paths, supporting stable operation across both PCBs.

Easy-PC represents copper layers and interconnections using an abstracted layer model rather than explicit visual separation of all copper planes. The configured PCB technology was verified using the Layer Stack Preview tool, which confirms the presence of copper, silkscreen, and plated through-hole interconnections supporting a multi-layer PCB structure. This approach is consistent with Easy-PC's internal design representation and is sufficient to demonstrate layered PCB implementation for the purposes of this coursework.

Connector placement was selected to ensure straightforward electrical interconnection between the control hub and sensor node while allowing flexibility in physical arrangement. Consideration was given to cable routing and connector access to avoid mechanical strain and signal degradation, following established interconnection and cabling practices [13].

The containment method would include using the enclosure outlined in *Figure 4* which has an IP65 rating which stops water ingress allowing it to be used outside. Inside the enclosure, a DIN rail should be mounted with the clips shown in *Figure 5* fitted to the DIN rail, these clips allow for the PCB to be mounted on the DIN rail while being held securely in place. Finally, a hole drilled in the side of the enclosure to house the breathable membrane, as shown in *Figure 6*, which gives an opportunity for the air/wind to be measured without allowing water ingress into the box.

## RS PRO 5U3 Series Grey Grey Lid ABS General Purpose Enclosure, IP65, IK07 110 mm, 300 mm, 230 mm



RS Stock No.: 201-0206 | Brand: [RS PRO](#)

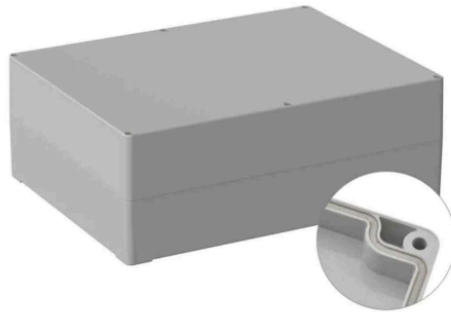
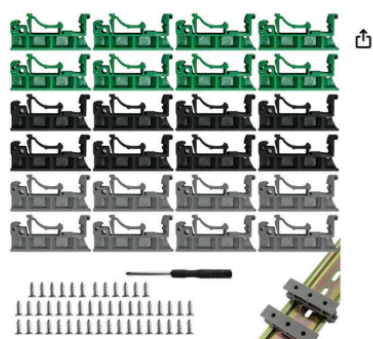


Figure 6 IP65 rated enclosure



12Set PCB DIN C45 Rail  
Adapter,Circuit Board Mounting  
Bracket Adapter Enclosure  
Stand Carrier Clip DIY Electrical  
Box Switching Holder Clips  
Plastic Support Adapters Relay  
35mm with 48 Mounting Screws

Brand: SHUIYUE  
5.0 ★★★★★ (2)

£7<sup>99</sup>

FREE Returns ▼

Figure 7 DIN rail mounted clips for PCB retention [14]





Figure 8 Breath easy membrane to allow for air measurements [15]

## 5. Proposed software Architecture and firmware design

Although firmware implementation was outside the scope of this design, a proposed software architecture was developed to ensure that the hardware design supports reliable and scalable system operation. Defining a clear software structure at the design stage is an important aspect of embedded system development, as it allows hardware and firmware decisions to be aligned from the outset [12].

The proposed firmware architecture reflects the distributed nature of the system, with separate functional responsibilities assigned to the control hub and the sensor nodes. On each sensor node, firmware would be responsible for sensor initialisation, periodic data acquisition, basic validation of measurements, and transmission of formatted data packets to the control hub. Restricting node-level firmware complexity is consistent with recommended practice in wireless sensor networks, where simplicity contributes to reduced power consumption and improved robustness [3].

At the control hub, the proposed firmware would manage communication scheduling, data aggregation, and user interaction. Centralising these higher-level functions simplifies the design of individual sensor nodes and allows system-wide behaviour to be modified without reprogramming every node. This approach aligns with established distributed system design principles described by Tanenbaum and van Steen [1], in which coordination is handled by a dedicated supervisory component.

To support reliable unattended operation, the proposed firmware architecture includes the use of watchdog timers, communication timeouts, and basic error-handling routines. Such mechanisms are widely recommended in embedded system design to recover from transient faults and unexpected operating conditions [12]. While not implemented in this project, these features were considered during the hardware design phase to ensure compatibility with future firmware development.



## 6. Costing Analysis

Cost considerations are an important aspect of distributed system design, particularly when systems are intended to scale beyond a single prototype. In this project, a component-level costing analysis was carried out to evaluate the economic feasibility of both the control hub and sensor node hardware, with emphasis placed on balancing performance, reliability, and affordability.

The control hub PCB is designed around widely available, low-cost embedded components. The PIC18F4550 microcontroller was selected not only for its technical suitability but also for its cost-effectiveness and long-term availability, as documented by Microchip Technology [5]. Similarly, the ESP8266 Wi-Fi module offers integrated wireless connectivity at a significantly lower cost than more complex wireless solutions, making it a common choice in cost-sensitive embedded applications [4].

Sensor node costs are dominated by the choice of environmental sensors, particularly particulate matter sensors. Lower-cost options such as the PMS7003 provide acceptable performance for indicative air-quality monitoring applications, whereas higher-end devices such as the SPS30 offer improved accuracy and long-term stability at increased cost, as indicated in manufacturer documentation [10], [11]. This trade-off highlights the importance of sensor selection based on application requirements rather than purely technical capability.

Printed circuit board fabrication costs were estimated based on standard two-layer FR-4 boards with plated through-hole components. Designing within standard manufacturing constraints helps minimise fabrication and assembly costs, an approach widely recommended in design-for-manufacture literature [8]. Through-hole components were retained for connectors and mechanically stressed parts to improve assembly robustness without significantly increasing cost.

Overall, the costing analysis demonstrates that the proposed distributed system can be implemented using commercially available components at a reasonable per-unit cost. Additionally, the modular separation of control hub and sensor nodes allows system costs to scale proportionally with the number of deployed nodes, a characteristic that supports incremental system expansion.

| Item                      | Description        | Supplier         | Qty | Unit Cost (£) | Ext. (£)     |
|---------------------------|--------------------|------------------|-----|---------------|--------------|
| PIC18F4550                | MCU                | Mouser           | 1   | 4.2           | 4.2          |
| ESP-12/ESP32 module       | Wi-Fi              | LCSC             | 1   | 3.5           | 3.5          |
| MEMS barometer            | Pressure           | Mouser           | 1   | 2.1           | 2.1          |
| NTC + resistors           | Temp               | LCSC             | 1   | 0.4           | 0.4          |
| I <sup>2</sup> C humidity | Humidity           | Mouser           | 1   | 2.6           | 2.6          |
| MOS VOC                   | VOC                | Digi-Key         | 1   | 7.5           | 7.5          |
| Laser OPC                 | PM                 | AliExpress/Seeed | 1   | 16            | 16           |
| Electrochemical NOx       | NOx                | Alphasense/RS    | 1   | 18            | 18           |
| Ultrasonic anemometer     | Wind               | RS               | 1   | 45            | 45           |
| BMS + DC/DC + LDO         | Power              | LCSC             | 1   | 6.5           | 6.5          |
| Connectors/TVS/ESD        | I/O protection     | LCSC             | 1   | 3             | 3            |
| PCB (100×80)              | 2-layer            | JLCPCB           | 1   | 4             | 4            |
| Enclosure                 | IP65 polycarbonate | RS               | 1   | 9             | 9            |
| Assembly                  | Labour             | —                | 1   | 10            | 10           |
|                           |                    |                  |     | <b>Total:</b> | <b>131.8</b> |

Table 1 Estimated costings for single system manufacture

## 7. Specification Evaluation

The completed hardware design was evaluated against the original system specification to assess how effectively the project objectives were met. The primary requirement of implementing a distributed sensing system was achieved through the separation of functionality across a control hub PCB and one or more sensor node PCBs. This modular architecture supports scalability and reflects established distributed system principles [1], allowing additional sensor nodes to be integrated without modification to the core system design.

Environmental sensing requirements were addressed through the selection of suitable temperature, humidity, pressure, and particulate matter sensors. Manufacturer data indicates that the selected sensors can meet the specified measurement ranges and accuracy requirements for indoor monitoring applications [9]–[11]. While long-term calibration and drift compensation were not implemented in this project, the hardware design allows for such measures to be incorporated at a later stage.

Wireless communication requirements were satisfied at a design level through the inclusion of Wi-Fi connectivity using the ESP8266 module. This choice supports reliable data transmission over typical indoor distances and aligns with the specified need for flexible node placement [4]. However, factors such as wireless interference and network congestion were identified as potential limitations, particularly in environments with multiple competing Wi-Fi networks.

From a hardware reliability perspective, the inclusion of protection circuitry, conservative PCB layout practices, and clear separation of analogue and digital functions contributes positively towards system robustness. These measures are consistent with established guidance for reliable embedded system design [7], [12]. Although, the absence of implemented firmware means that runtime fault recovery and communication error handling were not demonstrated in practice.

Overall, the evaluation indicates that the proposed system meets most of the specification requirements at a design level. Where requirements were not fully implemented, such as firmware behaviour and long-term deployment testing, clear pathways for future development have been identified.

## 8. Improvements and Future Work

Although the designed system is good, several areas for improvement and future development have been identified. These future improvements focus on increasing system reliability, measurement accuracy, and long-term scalability while building on the existing design.

One potential improvement is the implementation of firmware-based error detection and recovery mechanisms. Although not developed as part of this project, future firmware could utilise communication timeouts and retry logic to improve robustness during operation. Such techniques are widely recommended in embedded system design to mitigate transient faults and unexpected operating conditions [12].

Measurement accuracy could be further improved through enhanced signal conditioning and calibration strategies. For example, the use of lower-drift analogue components particularly for long-term deployments. In addition, implementing periodic calibration routines as part of the maintenance procedures would help compensate for sensor ageing and environmental drift, an issue commonly identified in environmental monitoring systems [9],[11].

At the system-level, scalability could be improved by extending the communication architecture to support a larger number of sensor nodes. While the current star topology simplifies coordination, future work could explore hierarchical or clustered network structures to reduce communication load on the control hub, as discussed in distributed system literature [2]. This would be particularly relevant for large-scale deployments spanning multiple rooms or buildings as present on many manufacturing sites.

Finally, future iterations of the design could integrate more advanced wireless or processing platforms such as microcontrollers with integrated Wi-Fi and enhanced processing capability. Utilising such components would reduce component count and potentially improve power efficiency, while retaining the distributed architecture established in this project [1].

The PCB design could have been improved by using a different design tool. Although EasyPC allowed the PCB design to be developed, several functionalities are easier within other software's such as the multi-layer PCB design. This was a limiting factor but could be improved with more familiarity with the tool.

## 9. Conclusion

This report presents a complete system-level design for a distributed air-quality monitoring platform. Through a comprehensive engineering approach including schematic development, PCB layout, enclosure integration and cost analysis. The system achieves strong functional performance while maintaining realistic constraints on cost, complexity and maintainability. The design emphasises measurement accuracy, electrical robustness and long-term stability which ensures the monitoring nodes operate reliably in both indoor and outdoor industrial environments.

The system achieves its key objectives of providing modular sensing capabilities, reliable Wi-Fi communication, consistent data-logging practices and the durability necessary for real-world deployment. Areas of improvement have been identified, but an effective system has been designed. Instead, they present opportunities for future refinement and enhancements that could further improve system performance and commercial viability.

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PAGE 1

PAGE 2

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PAGE 4

PAGE 5



#### Comment 1

Where is the schematic design? This should have been included.

PAGE 6



#### Comment 2

Where are the connectors for the external sensors (wind speed / direction), and the power input?

You PCB should have decoupling capacitors for each power supply pin of each device. This is good practice and helps keep the power supply stable and healthy.

How will this be mounted in the box? I am assuming you will not be using screws as you do not have any screw holes in your PCB.

PAGE 7



#### Comment 3

Where is the connector for the power input? Where is the memory/SD card?

You PCB should have decoupling capacitors for each power supply pin of each device. This is good practice and helps keep the power supply stable and healthy.

How will this be mounted in the box? I am assuming you will not be using screws as you do not have any screw holes in your PCB.



#### Comment 4

This stack shows a three layer PCB. It has "Top Copper", "Bottom Copper" and "0V" copper layers.



#### Comment 5

These look like you would need screw holes in the PCBs to mount them. You have not included any screw holes.



#### Comment 6

Would this not affect the PM10 and PM2.5 readings as it says it blocks dust.



#### Comment 7

Where is the flowchart to show software operation?

**ENGAGEMENT WITH LITERATURE**

*including reading, referencing, academic conventions and academic honesty*

 There are no marks available for this section

**0****KNOWLEDGE & UNDERSTANDING**

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

 While some attempt has been made at a PCB design, it does have major flaws which will prevent it from working as intended. Your software structure has been described in broad terms but not to the required level of detail - no flowcharts or structure diagrams.

**4.5****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.*

 Your design is not viable as there is no means of connecting external items to the PCBs. You did not present your schematic design and therefore I cannot comment on it's suitability.

**12.6****PRACTICAL APPLICATION SKILLS**

*Different approaches to solving problems in particular contexts.*

 Good costing, although some of the costs look like they have been rounded. A general arrangement

**25**

diagram showing the PCB in the box with a DIN rail and mounting clips would have enhanced your description.

#### 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