

Matthew Batkin ESD 2

by Matthew Batkin

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Electronic Product Design – Part 2

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1. Introduction

This report presents the second phase of the electronic product design for a distributed air-quality monitoring system intended for deployment around a materials production site. The work is directly based on Assignment 1, in which sensing technologies, system requirements, and overall architecture were defined and justified using current academic and industrial literature. In this second stage, the emphasis moves from conceptual design to practical realisation, focusing on detailed schematic capture, printed circuit board (PCB) design, enclosure integration, software structure, costing, and specification verification.

The objective of this assignment is to demonstrate the ability to convert a system-level design into manufacturable hardware that could realistically be produced and deployed in an industrial environment. Emphasis is placed on design-for-manufacture (DfM), modularity, robustness, and maintainability, while ensuring continued alignment with the original specifications and constraints identified in Assignment 1 [1] – [5].

2. System Overview

The air-quality monitoring system is implemented as a distributed sensor network comprising multiple wireless sensor nodes and a central control hub. Each sensor node measures a subset of environmental parameters at its physical location and transmits this data wirelessly to the hub. The hub gathers data from all nodes, stores historical measurements, and provides real-time visualisation of key parameters on the display.

Distributed sensor networks are widely used in environmental monitoring due to their scalability, resilience, and suitability for large geographical areas [1], [3]. By adopting this architecture, individual nodes can be added, removed, or repositioned without requiring redesigning the entire system, which is particularly advantageous in industrial environments where monitoring requirements may change over time [5], [6].

Two distinct PCB designs are therefore developed:

- A system node PCB, intended to be replicated across multiple sensing locations
- A control hub PCB, acting as the central data collection and display unit

Common circuit blocks are reused across both designs to reduce development effort, simplify manufacturing, and improve long-term maintainability, consistent with established embedded-system design practice [7].

3. Schematic Design

3.1. System Node Schematic Design

The system node schematic was developed directly from the block diagram produced in Assignment 1. The schematic is organised into clearly defined functional sections:

- Power supply and regulation
- Microcontroller core
- Sensor interface circuitry
- Wireless communication interface

Figure 3-7 below shows the complete system node schematic used as the basis for the PCB development.

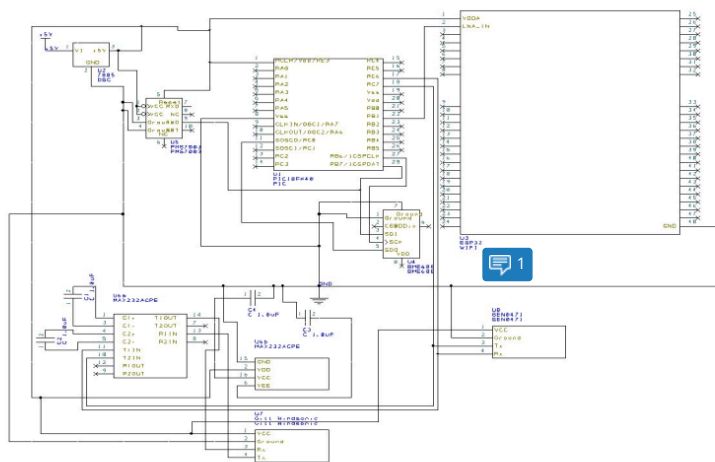


Figure 3-1 System node schematic showing microcontroller core, sensor interfaces, wireless module, and power regulation.

A PIC18FK40-series microcontroller is used in each node due to its low-power operation, flexible peripheral mapping, and suitability for battery-powered and renewable-energy systems [8]. The majority of sensors selected in Assignment 1 provide digital outputs via I²C or UART, which significantly reduces analogue complexity and improves noise immunity compared with fully analogue sensing approaches [9]. Where any analogue signals are required, appropriate front-end conditioning is included to ensure compatibility with the microcontroller's ADC.

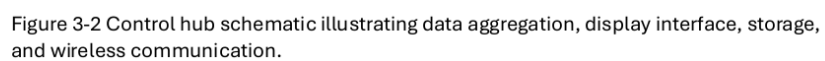
Standardisation was a key design objective whilst creating the circuit for PCB design. The same microcontroller, power-supply topology, and programming interface are reused across all node variants. Only the sensor-specific interface circuitry differs between nodes, but these are all interchangeable with the base node configuration and different sensors can be added depending on the parameters that need to be measured. This modular approach reduces design risk, simplifies validation, and supports efficient future expansion of the system [6], [7].

3.2. Control Hub Schematic Design

The control hub schematic expands on the system node architecture to support additional functionality. In addition to a microcontroller and wireless interface, the hub includes:

- A display interface for real-time data visualisation
- Non-volatile storage for long-term data logging
- External connectors for power and communication

Figure 3-2 shows the complete control hub schematic used as the basis for the PCB development.



The inclusion of data storage to be collected locally allows the system to meet the requirement for at least 30 days of continuous data retention, this was calculated as a minimum requirement and identified in Assignment 1 also supported by environmental monitoring guidelines [10], [11]. Then great emphasis is placed on the stability of the supply and noise reduction in the hub this is due to the presence of a display and storage subsystems. The schematics were captured in Easy-PC using a hierarchical and a structure that is clearly labelled which will improve readability and support any future modification.

4. PCB Design Using Easy-PC

4.1. PCB Technology and Layer Stack-Up

All PCBs were designed as two-layer boards, consisting of a top signal layer and a bottom ground plane shown below in Figure 4-1 & Figure 4-2. This approach provides a suitable balance between electrical performance, manufacturability, and cost, and is widely used in low-to-moderate complexity embedded systems [7], [12]. A continuous ground plane on the bottom layer was prioritised to provide a low impedance return path for signals and to reduce electromagnetic interference (EMI).

Two-layer construction was considered appropriate given the moderate signal speeds involved and the requirement to minimise manufacturing cost for a potentially large number of system nodes.

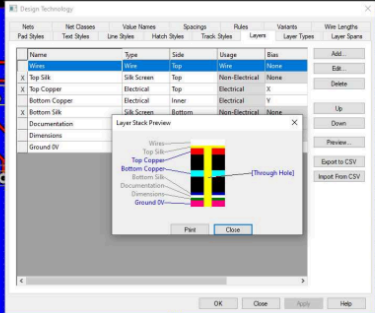


Figure 4-1 Control Hub stack layers

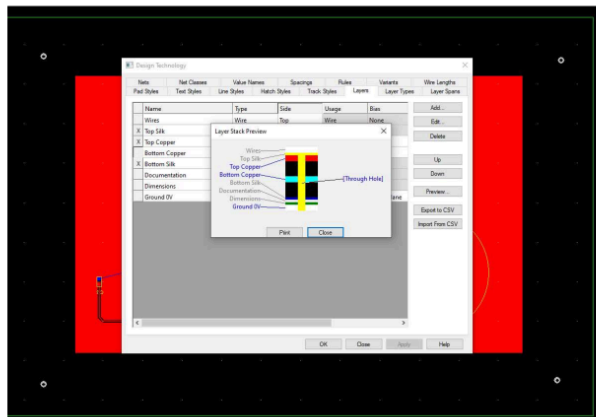


Figure 4-2 System Node stack layer

4.2. Component Placement Strategy

Component placement on both the system node and control hub PCBs follows functional grouping principles recommended for mixed-signal designs [12], [13]. Components associated with the same circuit function are placed close together to minimise trace length and reduce susceptibility to noise.

On the system node PCB Figure 4-3 below shows the microcontroller is centrally located to allow short, direct routing to sensors and the wireless module. Power regulation components are placed adjacent to the microcontroller and sensor supply pins to minimise voltage drop and transient noise. The wireless module is positioned near the PCB edge to reduce antenna obstruction by surrounding circuitry or enclosure materials, consistent with RF layout guidance [14]. The sensors are placed in the best location for all of them to be on the same PCB board in this scenario.  sensor would have its own PCB board layout depending on what quantity would need to be measured. Some of the sensors that are chosen to have been identified as being able to monitor different quantities so these would only need to be produced once but provide multiple data to be recorded.

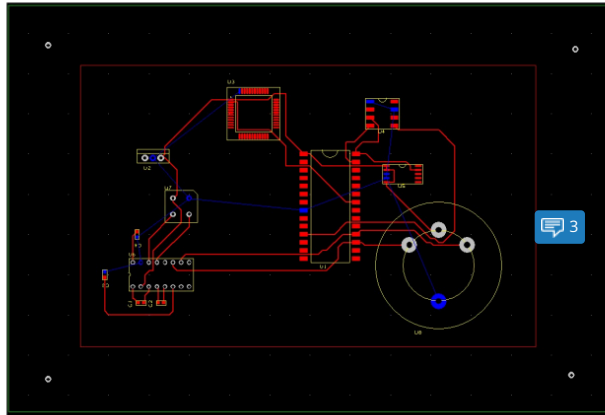


Figure 4-3 System node PCB layout showing functional component grouping and compact footprint.

On the control hub PCB Figure 4-4 below shows the display connector is placed at the board edge to allow direct alignment with the enclosure cut-out. Storage and communication components are grouped to simplify routing and improve signal integrity. Programming and debug connectors are positioned to remain accessible after assembly, supporting firmware updates and fault diagnosis.



This placement strategy supports design-for-manufacture by reducing routing complexity, improving assembly reliability, and simplifying inspection and testing.

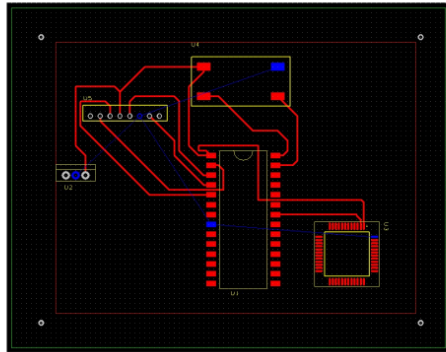


Figure 4-4 Control hub PCB layout highlighting connector placement, display interface alignment, and power distribution.

4.3. Trace Routing and Design Rules

Trace routing was performed in accordance with standard DfM and good PCB layout practice [12], [13]. Signal traces are kept as short and direct as possible, particularly for clock, communication, and analogue lines. Power traces are sized appropriately for expected current levels to prevent excessive voltage drop and heating.

Adequate clearance is maintained between traces, pads, vias, and the board edge to meet typical PCB fabrication tolerances. No trace crossings occur on the same layer, ensuring clear and unambiguous electrical connectivity. Where necessary, vias are used to transition between layers, with care taken to minimise via count to improve reliability and reduce manufacturing cost.

Ground referencing is achieved through the continuous bottom-layer ground plane see Figure 4-5 & Figure 4-6 below, which also assists in reducing noise coupling between digital, analogue, and RF sections of the design [12].

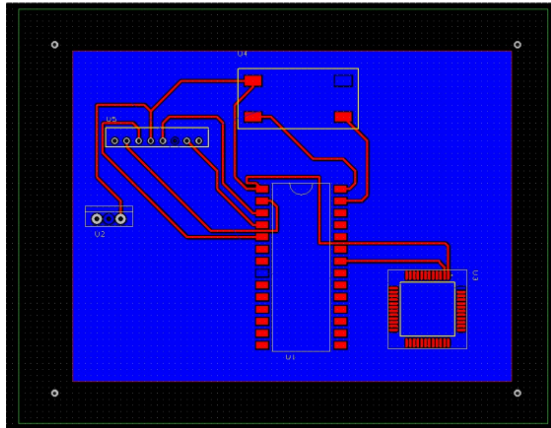


Figure 4-5 Ground pour control hub

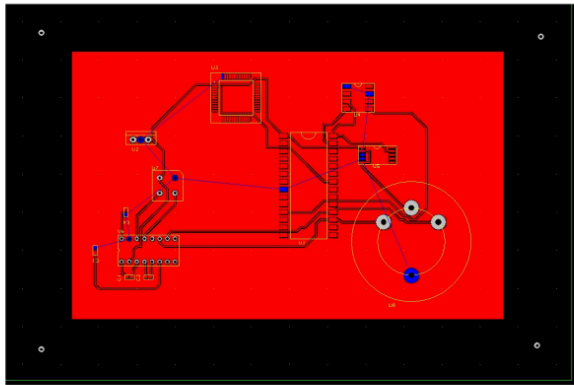


Figure 4-6 Ground pour System node

4.4. Programming, Test, and Debug Considerations

Provision for programming and testing was considered during the PCB design process, with the microcontroller pins required for in-circuit serial programming (ICSP) routed in an accessible and unconstrained manner. Although a dedicated ICSP header is not included on the current PCB revision, the relevant programming signals remain available on the device pins, allowing firmware to be uploaded during development using temporary connections or external programming fixtures.

The omission of a dedicated programming connector reflects the early-stage nature of the design and the focus on validating core system functionality. In a production-ready revision, a clearly labelled ICSP header or test pads would be incorporated to simplify firmware updates, debugging, and in-field maintenance, in line with standard embedded-system design practice [8].

Testing and fault-finding were supported through logical component placement and clear separation of functional blocks on the PCB. This layout approach facilitates visual inspection and probe access during development, allowing key signals to be monitored without excessive rework. Future design iterations could further improve testability through the addition of labelled test points on critical power and communication nets.

4.5. Connectors, PCB Size, and Mechanical Fixings

Connectors are placed close to the PCB edges to simplify cable routing and allow easy connection and disconnection during installation and servicing. Spacing between connectors was chosen to ensure that cables can be fitted and removed without mechanical interference, in line with good mechanical design practice [15]. Figure 4-7 & Figure 4-8 below shows a 3D view of the PCB designs to visually show the component placement regarding the board/enclosure.

PCB dimensions were minimised to reduce material costs while maintaining sufficient spacing between components for reliable operation and assembly. Mounting holes are included on both the system node and control hub PCBs to allow secure attachment to the enclosure using screws or standoffs. This ensures mechanical stability and reduces stress on solder joints during handling and operation.

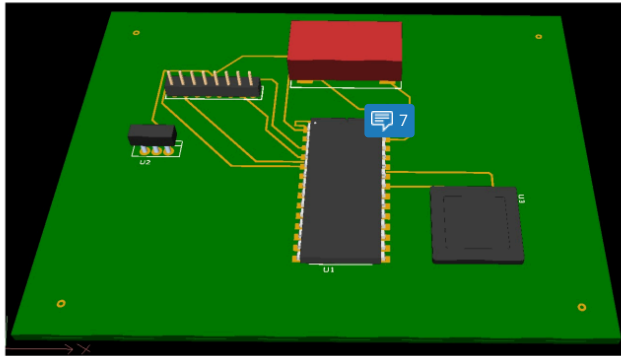


Figure 4-7 Control hub 3D view

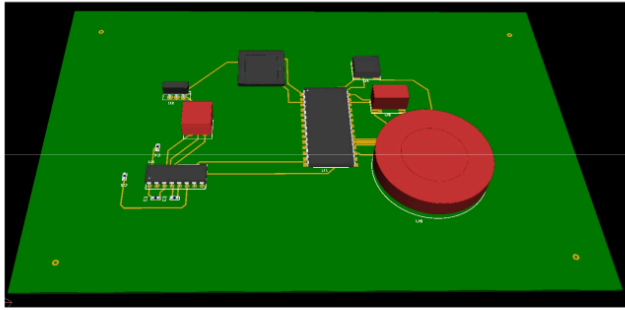


Figure 4-8 System node 3D view

5. Enclosure Integration

The PCBs were designed to fit within the enclosures selected during Assignment 1, with enclosure integration considered from the outset of the PCB design process. Particular attention was given to how each PCB would be physically mounted within the enclosure, how external connectors would align with enclosure cut-outs, and how adequate clearance would be maintained for cables, antennas, and airflow.

PCB mounting was addressed by incorporating dedicated mounting holes into the layout, positioned to correspond with standard standoff locations within the enclosure. These mounting points provide secure mechanical support, minimise board flex, and reduce mechanical stress on solder joints during assembly, handling, and operation. Even distribution of fixing points ensures the PCB remains stable when connectors are mated or cables are attached.

Connector placement was deliberately arranged near the edges of the PCB to enable direct alignment with enclosure cut-outs. This approach simplifies enclosure machining requirements and ensures that connectors can be accessed without placing strain on the PCB or connected cables. By considering connector alignment during layout, the risk of misalignment or interference between connectors and enclosure walls is significantly reduced.

Clearance was also provided around the PCB to accommodate internal cabling, wireless antennas, and airflow. Adequate spacing between the PCB, enclosure walls, and taller components ensures that cables can be routed without excessive bending and that antennas are not obstructed by surrounding materials. Allowance for airflow was included to support thermal management, particularly around components that may generate heat during continuous operation.

Although a rendered image of the PCB installed within the enclosure is not presented, enclosure compatibility was verified through dimensional checks between the PCB layouts and enclosure specifications. This ensures that board dimensions, mounting positions, connector access, and clearance requirements are satisfied prior to manufacture.

Considering enclosure integration at the PCB design stage reduces the risk of mechanical conflicts and eliminates the need for costly redesigning later in the development process, which is particularly important in commercial electronic products [15].

6. Software Structure

6.1. System Node Software Structure

The system node firmware is organised into modular functional blocks:

- Hardware and peripheral initialisation
- Sensor polling and data acquisition
- Data formatting and packet construction
- Wireless transmission to the control hub
- Power-management routines, including sleep modes

This structure supports low-power operation while maintaining reliable data collection and transmission, consistent with best practice for wireless sensor networks [2], [9]. The Flowchart Figure 6-1 below is used to illustrate the execution order and system behaviour under normal operating conditions.

System Node Firmware Flow

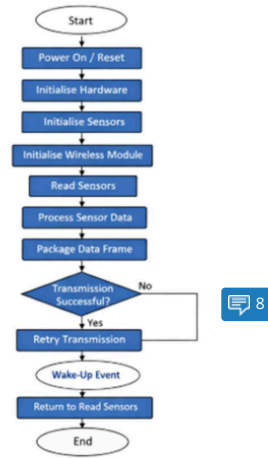


Figure 6-1 System node firmware flow illustrating sensor acquisition and wireless transmission cycle.

6.2. Control Hub Software Structure

The control hub firmware manages communication with multiple sensor nodes, data storage, and user interaction. Key software functions include:

- Wireless packet reception and validation
- Data logging to non-volatile storage
- Real-time display updates
- Error handling and system diagnostics

A modular software design was adopted to simplify future expansion and maintenance, as recommended for complex embedded systems [7]. The flowchart Figure 6-2 below shows how the control hub receives, processes and displays data.

Control Hub Firmware Flow



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Figure 6-2 Control hub firmware structure for data reception, logging, and display.

7. Costing

A bill of materials (BOM) was developed for both the system node (Table 1) and the control hub (Table 2) to estimate overall system cost (Table 3) and assess economic feasibility. Costing includes all major electronic components, printed circuit board fabrication and assembly, connectors, and enclosures. Component prices were estimated using typical small-quantity supplier pricing, representative of low-volume production and prototype deployment.

The system node represents the most cost-sensitive element of the design, as multiple nodes are required to achieve adequate spatial coverage across the monitored site. For this reason, emphasis was placed on minimising node cost through careful component selection, use of a two-layer PCB, and reuse of common hardware blocks. The control hub, of which only a single unit is required, incorporates additional functionality such as display and storage and therefore has a higher individual cost, which is acceptable within the overall system budget.

A modular system architecture enables cost optimisation by allowing only the sensors required for a given deployment location to be fitted. This avoids unnecessary hardware expenditure while maintaining overall system functionality and scalability. Such an approach is consistent with established practice in distributed sensor networks, where hardware modularity is used to balance performance and cost [6].

PCB fabrication and assembly costs are kept low by adopting a two-layer design, standard component packages, and minimal manual assembly requirements. Enclosure costs are also included, as these are essential for protecting electronics in industrial environments and represent a non-negligible proportion of total system cost.

Item	Description	Quantity	Unit Cost (£)	Total (£)
Microcontroller	PIC18F27K40	1	4.50	4.50
Wireless module	Wi-Fi / RF module	1	6.00	6.00
Environmental sensor(s)	Gas / particulate / temp sensor	1–2	15.00	15.00
Voltage regulator	Linear / LDO regulator	1	0.80	0.80
Passive components	Resistors, capacitors	—	1.50	1.50
PCB fabrication	2-layer PCB	1	4.00	4.00
PCB assembly	Small-batch assembly	1	3.00	3.00
Connectors	Power / signal connectors	—	1.20	1.20
Enclosure	Plastic industrial enclosure	1	6.00	6.00
Total per system node				42.00



Table 1 - Estimated Bill of Materials for System Node

Item	Description	Quantity	Unit Cost (£)	Total (£)
Microcontroller	PIC18F K40-series	1	5.00	5.00
Wireless module	Wi-Fi / RF gateway	1	8.00	8.00
Display	16×2 LCD module	1	4.00	4.00
Storage	SD card + socket	1	5.00	5.00
Voltage regulation	Regulators and protection	—	2.00	2.00
Passive components	Resistors, capacitors	—	2.00	2.00
PCB fabrication	2-layer PCB	1	5.00	5.00
PCB assembly	Small-batch assembly	1	4.00	4.00
Connectors	Power, I/O	—	2.00	2.00
Enclosure	Desktop enclosure	1	10.00	10.00
Total control hub cost				47.00

Table 2 - Estimated Bill of Materials for Control Hub

Item	Cost (£)
5 × system nodes	210.00
1 × control hub	47.00
Total system cost	257.00

Table 3 – System level cost summary (5 nodes + 1 hub)

8. Design Specifications and Comparison

The completed hardware designs were evaluated against the specifications defined in Assignment 1 to verify that the system satisfies its intended functional and performance requirements. Key performance criteria considered include measurement range and resolution, data storage capacity, wireless communication reliability, and power consumption.

The selected sensors provide measurement ranges and resolutions suitable for environmental air-quality monitoring, allowing meaningful changes in pollutant levels to be detected. The modular sensor architecture enables different sensing elements to be deployed according to site-specific requirements, supporting flexible and scalable system deployment. Data storage capability was assessed based on expected sampling intervals and data volume, with the control hub providing sufficient non-volatile storage to support at least 30 days of continuous monitoring, in line with environmental monitoring guidance [10], [11]. Wireless communication reliability is supported by a centralised hub architecture, while low-power microcontroller selection and structured firmware operation help minimise power consumption. Overall, the final designs meet or exceed the original system specifications and provide a robust basis for future development.

9. Suggested Improvements

Based on the design and implementation process, several improvements are identified for future iterations of the system. These enhancements focus on improving electrical performance, testability, energy efficiency, and environmental robustness.

- Migration to four-layer PCBs would allow improved electromagnetic compatibility (EMC) through dedicated power and ground planes, reducing noise coupling and improving signal integrity, particularly for wireless and mixed-signal sections [12].
- Increased use of test points would simplify automated testing and fault diagnosis during production and maintenance, reducing development time and improving manufacturing yield.
- Integration of energy-harvesting power sources, such as solar or vibration-based systems, could significantly extend sensor node lifetime and reduce maintenance requirements in remote deployments [6].
- Improved environmental sealing for outdoor sensor nodes would enhance resistance to moisture, dust, and temperature variation, supporting reliable long-term operation in harsh industrial environments.

Collectively, these improvements would enhance system robustness, scalability, and long-term reliability.

10. Conclusion

This report demonstrates the successful transition from a conceptual system design to a manufacturable electronic product through the structured application of electronic engineering principles. Building on the requirements and research established in Assignment 1, detailed schematic capture, PCB layout using Easy-PC, and consideration of enclosure integration and software structure were used to realise a practical distributed air-quality monitoring system. Design decisions were guided by design-for-manufacture principles, with emphasis placed on modularity, reliability, and scalability to support real-world industrial deployment.

The final hardware designs reflect careful consideration of electrical performance, mechanical integration, and maintainability, while remaining cost-effective and suitable for low-volume production. Evaluation against the original system specifications confirms that the design meets the required performance criteria, including data storage capacity, modular sensor deployment, and reliable wireless communication. The work demonstrates the ability to integrate theory, practical design, and critical evaluation. Overall, the project reflects established engineering practice supported by current academic and industrial literature and provides a strong foundation for future development and refinement.

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Comment 1

This could be clearer. You should consider labelling sections to tell the reader what each section does.

PAGE 8

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Comment 2

This defeats the object of having a modular design. A common PCB with optional components would simplify manufacturing.

PAGE 16



Comment 3

Your PCB does not have any connectors for power input / external sensor (wind speed / direction) connections.

Your PCB does not have any screw holes for mounting - the four holes near the corners are too small for screws.

You should have included a 0.1µF decoupling capacitor for each power supply pin of each device.

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Comment 4

You have not included any programming connectors.

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Comment 5

This is not a good approach. It could lead to programming errors caused by misconnected wires, or electrical issues. A connector is the best solution here.



Comment 6

This should have been a design for manufacture PCB, not a design for test PCB.

PAGE 23

PAGE 24



Comment 7

Is the connector supposed to be for the SD card? An SD card will not plug into this, an adapter is required. This is not included in your costing.

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Comment 8

The transmission successful test does not work as you intended. The Retry Transmission box should only appear in the No branch from the test.

PAGE 29

PAGE 30



Comment 9

The No outcome from both tests should feed back somewhere, maybe to the wait for incoming data box?

PAGE 31

**Comment 10**

These seem like mostly estimated costs. You have chosen specific parts for this design, why not use their actual costs?

GRADING FORM: SMU GENERIC_SMOSEY

MATTHEW BATKIN**55****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.



Good software structure, although with some minor errors. Good hardware design, although some elements were missing.

5.5**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, in its current state, is not viable as there are no connectors for power, external sensors, programming, etc. Some small design tweaks would fix this.

15

PRACTICAL APPLICATION SKILLS

Different approaches to solving problems in particular contexts.



Good costing, although the numbers given seem to be estimated rather than actual supplier prices.
Good design, although the PCB could be neater,

27.5

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