Review the assignment due date

IoT Venture Pitch

ESE5180: IoT Wireless, Security, & Scaling

Team Name: Gatorade

Team Member Name	Email Address
James Steeman	jsteeman@seas.upenn.edu
Joaquin Revello Lerena	joaquinr@seas.upenn.edu
Chirag Satapathy	csat28@seas.upenn.edu

Weekly Meeting: Wednesday 7pm

GitHub Repository URL: https://github.com/ese5180/iot-venture-f25-gatorade

Concept Development

Product Function

Our smart HVAC system will integrate permanent sensors at key nodes throughout ductwork to continuously monitor air quality, VOC, humidity, then alert operators to deploy an AI-guided mobile robot for chemical-free cleaning using UV-C sterilization and adaptive brushing to achieve 99.99% pathogen elimination. The sensor network will predict contamination issues and guide operators to exact problem locations, while the lightweight bot will provide superior cleaning results in 30 minutes versus 2-3 hours for competitors. This intelligent system will deliver better performance at lower cost by combining continuous monitoring with smart operator guidance for targeted, efficient cleaning.

Target Market & Demographics

Who will be using your product?

- Facility managers at commercial buildings (offices, hospitals, schools, retail)
- HVAC technicians who will operate the AI-guided cleaning bot
- Building maintenance staff monitoring the sensor network dashboard
- Property managers overseeing multiple buildings

Who will be purchasing your product?

- Commercial building owners (office buildings, shopping centers, hotels)
- Healthcare facility administrators (hospitals, clinics, care facilities)
- Educational institutions (universities, school districts)
- Property management companies managing multiple commercial properties
- Data center operators requiring precise environmental control

Where in the world would you deploy your product?

- Primary markets: North America (US, Canada) - strict indoor air quality regulations
- Secondary markets: Europe (UK, Germany, Nordic countries) - high environmental standards
- Growth markets: Australia, Japan, Singapore - advanced building management adoption
- Future expansion: Major commercial centers in developing markets (Dubai, Hong Kong, major Chinese cities)

How large is the market you're targeting?

- Global HVAC services market: ~$200 billion annually

- Building management systems: ~$20 billion annually

- Indoor air quality monitoring: ~$5 billion annually growing 8%+ yearly

- Serviceable addressable market: ~$15-25 billion (commercial buildings with centralized HVAC)

- Target segment (50,000+ sq ft commercial): ~$8-12 billion annually

How much of that market do you expect to capture?

- Year 1-2: 0.01% = $1-2 million (pilot customers, proof of concept)
- Year 3-5: 0.1% = $10-25 million (regional expansion, established product)
- Year 5-10: 1-2% = $100-250 million (national presence, market leadership)
- Long-term potential: 5-10% = $500M-$1.2B (dominant platform with international expansion)

What competitors are already in the space?

Direct Competitors

- Teinnova Multibot - Professional duct cleaning robots ($50K+ equipment)
- JettyRobot S - Industrial pipeline inspection/maintenance ($100K+ systems)

Indirect Competitors

- Traditional HVAC cleaning services - Manual cleaning companies
- Smart building management systems - Johnson Controls, Honeywell, Siemens
- Indoor air quality monitors - Airthings, PurpleAir, Awair
- Smart HVAC filters - 3M Filtrete, Nordic Pure smart filters

Key Differentiation

No existing competitor combines continuous sensor monitoring with AI-guided mobile cleaning and chemical-free UV-C sterilization in a comprehensive building health management platform.

Stakeholders

We have reached out to several stakeholders, including emailing EOS at UPenn, and submitting web contact forms for LG and Hitachi, but have not solidified any individual stakeholder at this point.

Student Project: Request for Feedback on HVAC Inspection & Monitoring Concept

James Steeman <jsteeman@seas.upenn.edu>
to EOS, Chirag, Joaquin

Thu, Sep 25, 12:42 PM (1 day ago)

Hello,

My name is James, and I'm part of a student team in SEAS (the ESE 5180 course) considering an engineering project related to HVAC inspection and maintenance. As part of the project, we're looking for feedback to help us refine the idea and understand what aspects are most valuable (and what might be unnecessary). If someone on your team is available to share some thoughts, we'd greatly appreciate it.

The inspection portion of the idea is a robot that navigates through HVAC ducts to detect issues such as mold, debris, blockages, corrosion, and wear. It would then generate or update a system map and prepare work orders. This could also be equipped with cleaning elements like a brush or vacuum unit for dust/debris removal, and perhaps a UV cleaning element.

Additionally, the robot would place compact sensor nodes throughout the system to provide real-time and continuous monitoring of temperature, humidity, vibration, or other desired parameters to help identify developing issues, support air quality compliance, and enable predictive maintenance.

We believe that this could both help with maintenance of newer systems and reduce costs by proving that older HVAC systems can remain in service with targeted maintenance, rather than requiring full replacement. It could also offer facility managers more information to use in decision making processes

Since we don't have any experience working with or maintaining such systems, we're hoping to better understand which parts of this idea would be most useful in practice, and what challenges it could face in real-world deployment? Are there already techniques used to facilitate inspection and monitoring tasks, and if so, how might this idea fit in with those?

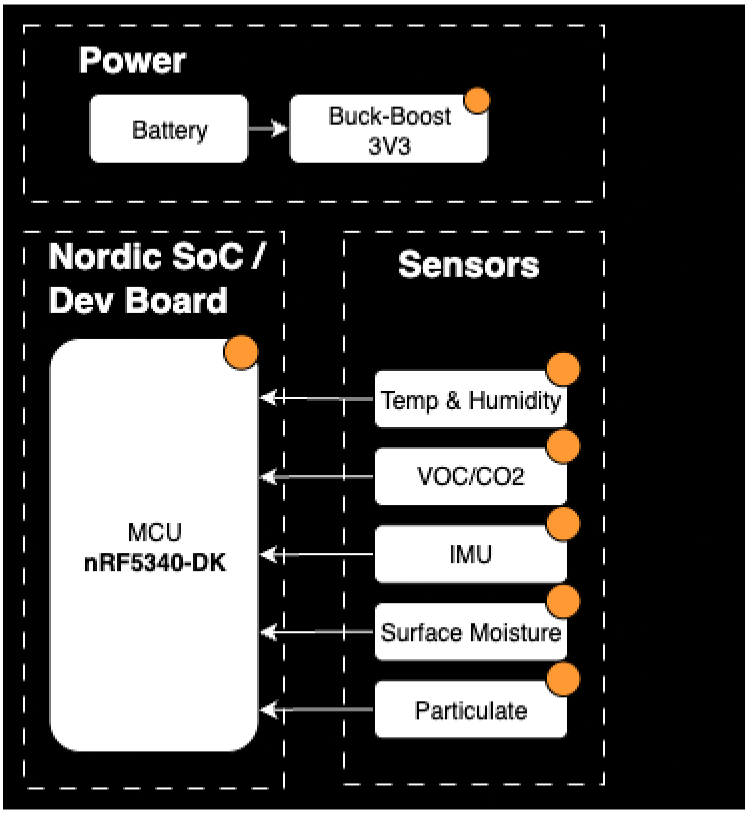
Thank you for your time and help!

Best,
James Steeman
EE '26

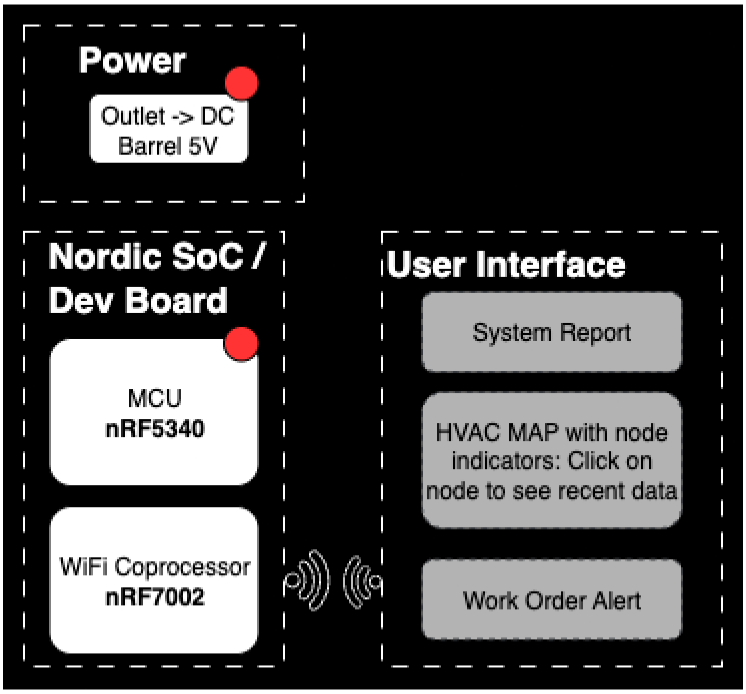
Since we believe the current idea of our product will be more directed towards HVAC companies and building managment than maintenance staff, we continuing to reach out to additional companies (through sales departments) for feedback on our idea.

System-Level Diagrams

Sensor Node

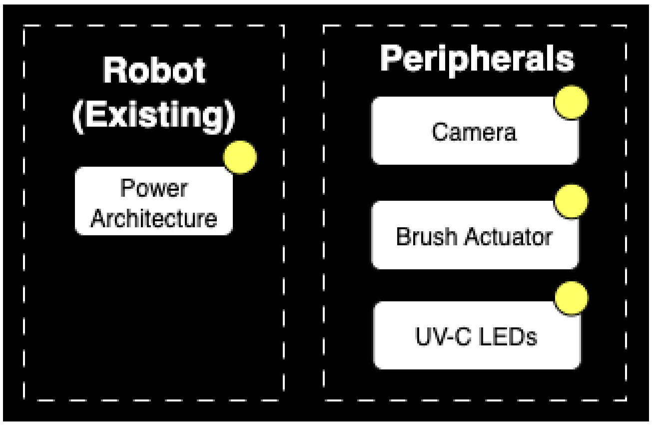


Gateway



Robot

We will start by leveraging an existing robot and prototyping on top/hacking the robot to add cleaning functionality. Below is a very simple diagram indicating our added peripherals, which we will first attempt to power from the robot's power architecture, but add external battery/power management if necessary.



Security Requirements Specification

Security Overview

The system will ensure data, communications, and firmware integrity are protected from tampering, eavesdropping, and unauthorized access. Security measures particularly focus on safeguarding the gateway and nodes, which are in continuous operation and not always being observed.

Security Definitions, Abbreviations

- OTA: Over the air firmware updates
- GUI: Graphic User Interface

Security Functionality

Requirement ID	Requirement Title	Description	Rationale
SEC 01	Gateway Firmware Integrity	Gateway shall run only firmware from signed OTA updates, and shall securely store keys	The gateway acts as a bridge between the sensor node mesh network and the cloud (data portal etc.), and compromise here could expose the client's network and leave them vulnerable to attacks and breaches
SEC 02	Autheticate Nodes	Each sensor node shall authenticate in the mesh network using unique key/certification and ignore messages from tampered systems	This prevents unauthorized devices from disrupting the mesh or tampering with the data at the hardware level. It also protects from counterfit devices being added to our network
SEC 03	Data Encryption	Communication from nodes, gateway and GUI interface shall be encrypted	This protects potentially sensitive IAQ and predictive maintenance data from eavesdropping and tampering at the data level

Hardware Requirements Specification

Hardware Overview

The system contains a mobile robot for HVAC navigation, duct cleaning operations and sensor node depolyment. Low power sensor nodes will be deployed in the HVAC system for data collection to identify system issues and enable predictive mainenance. There will also be a gateway node.

Hardware Definitions, Abbreviations

- HVAC: Heating, Ventilation, and Air Conditioning
- VOCs: Volatile Organic Compounds
- UV-C: Ultraviolet C - short-wavelength UV light used for chemical-free disinfection and sterilization

Hardware Functionality

Requirement ID	Requirement Title	Description	Rationale
HRS 01	Bot Size and Weight	The mobile bot shall be maximum 300mm x 100mm x 100mm (can change) and weigh less than 5kg to fit through standard commercial ductwork.	Must navigate existing HVAC systems without modifications or damage.

Requirement ID	Requirement Title	Description	Rationale
HRS 02	UV-C Sterilization	The bot shall include UV-C LEDs with 360-degree coverage to achieve 99.99% pathogen elimination.	UV-C sterilization is the core technology differentiator for chemical-free cleaning.
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HRS 04	Wireless Communication	System shall maintain mesh networking with 100m range and <2 second response time between sensors and bot.	Real-time monitoring and response is critical for building health management.
HRS 05	Camera System	The bot shall include HD cameras with LED illumination for visual inspection and AI-powered contamination detection in low-light ductwork environments.	Visual documentation and AI analysis are essential for contamination identification and compliance reporting.

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Software Overview

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The robot software shall collect and process real time controls and data for navitagion and cleaning operations.

Software Users

- Facility managers at commercial buildings (offices, hospitals, schools, retail) using IoT dashboard
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Software Abbreviations

- MCU: Microcontroller Unit

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Pitch 1

Course Pitch 1 Slides

Wireless Demo

Gateway Repo

Mesh Node Repo

We have pulled and compiled the code on the different machines.

We have ordered sensors and the seeed studio XIAO nRF54L15 (s) for our ble mesh nodes.

Concept Refinement

Concept Review & Refresh

Description

Our smart HVAC system integrates permanent sensor nodes throughout ductwork to continuously monitor air quality, VOCs, and humidity. Each node uses force air power generation to recharge its battery, enabling long-term autonomous operation. When contamination is detected, operators are alerted to deploy a mobile cleaning unit that uses UV-C sterilization and adaptive brushing to achieve pathogen elimination. The system predicts issues, pinpoints problem areas, and delivers superior cleaning in less time versus 2–3 hours for competitors—offering continuous monitoring and targeted, efficient cleaning at lower cost.

Product Function

Our proposed solution is an integrated smart HVAC management system to continuously monitor HVAC system health using distributed sensor nodes and maintain the system with deployable guided cleaning robots. The network of permanent sensors embedded in ductwork measures VOC levels, humidity, and particulate contamination in real time, transmitting data to a central dashboard, from which operators can make data driven decisions. If abnormal readings are detected, the system provides alerts and guidance. The compact mobile cleaning robot is equipped with UV-C sterilization lamps and adaptive brushes to disinfect and remove buildup without chemicals while navigating autonomously through ducts. By combining predictive analytics from the sensor network with targeted robotic cleaning, the system transforms HVAC maintenance from a reactive to a proactive process. Facility managers can visualize air quality trends, schedule cleanings efficiently, and verify cleanliness with post-cleaning validation data. The chemical-free, automated process not only improves IAQ and system performance but also reduces operational costs and downtime. This integrated approach is a scalable, eco-friendly, and data-driven solution meeting modern building health and sustainability standards while offering a ROI through reduced maintenance time and energy savings.

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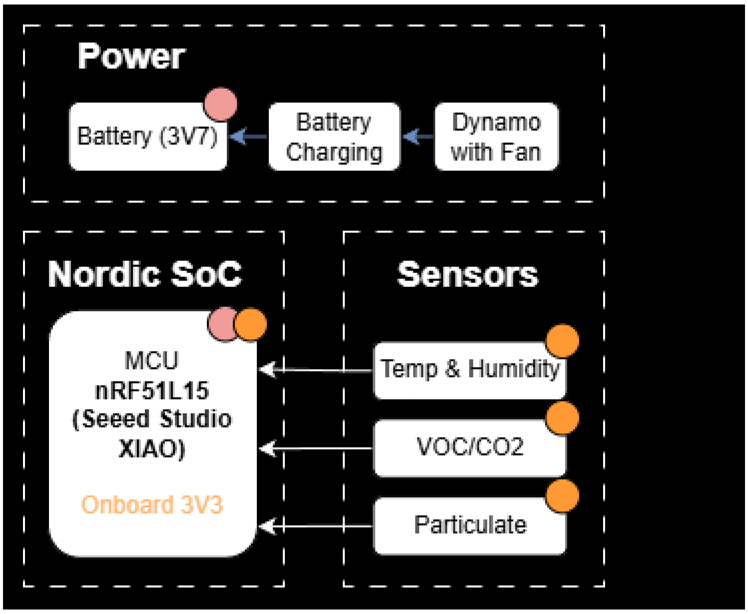

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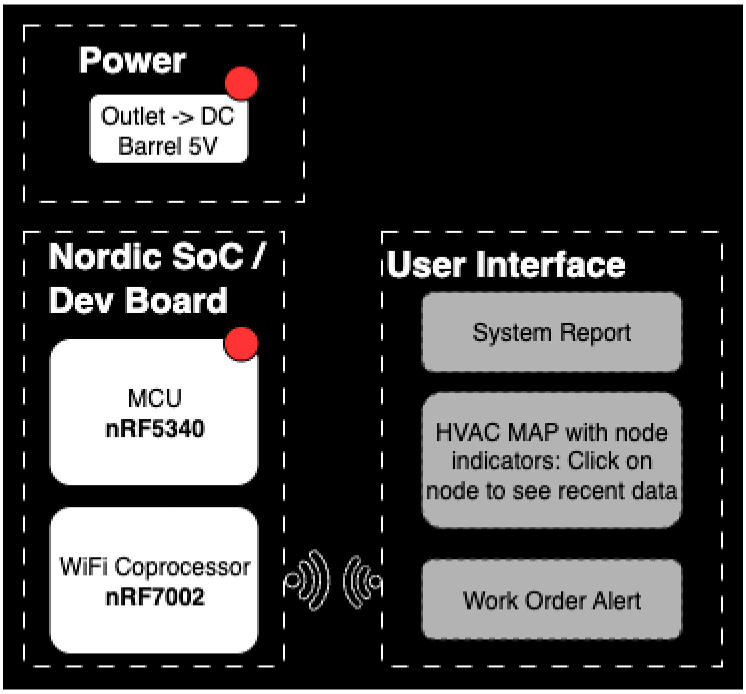

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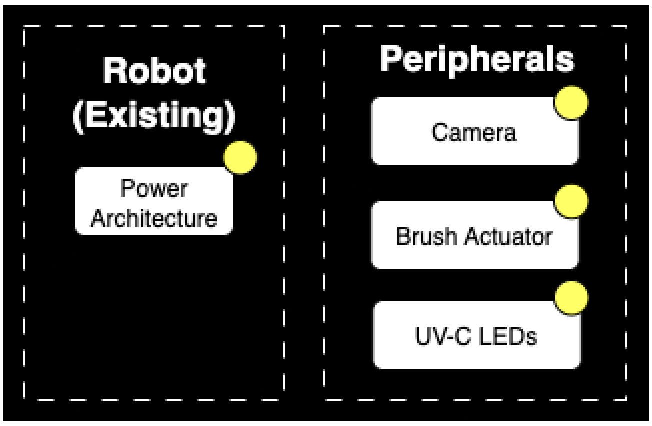

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Create a rough power budget for your end device

HVAC Sensor Node — Power Budget

The node uses airflow (forced air) inside the duct to harvest power while measuring air quality and environmental parameters.

System Overview

Components:

- nRF54L15 Microcontroller (BLE)
- SPS30 PM2.5 Sensor
- BME680 Temperature, Humidity & Gas Sensor
- 3.7V 4500mAh Li-ion Battery
- LiPo Charger Module
- Airflow Dynamo (3–12V, 1500 RPM) for energy harvesting

Sampling Interval: Every 10 minutes
Airflow Velocity (assumed): 5 m/s
Regulator Efficiency: ~90%

Power Consumption Breakdown

Component	Active Current	Active Time per Cycle	Duty Cycle	Avg. Current
nRF54L15 (MCU + BLE)	5 mA	0.5 s	0.083%	0.004 mA
SPS30 PM2.5 Sensor	60 mA	30 s	5%	3.0 mA
BME680 Sensor	1 mA	1 s	0.167%	0.002 mA
Regulator & Misc Losses	-	-	-	0.10 mA
Total Average (3.3V Rail)	-	-	-	**≈ 3.1 mA**

Average Power: 3.3V × 3.1mA = **10.2 mW**
Daily Energy Use: 10.2mW × 24h = **0.245 Wh/day**

Battery-Only Operation (No Harvest)

Battery: 3.7V, 4500mAh = 16.65Wh

Runtime = 16.65Wh / 0.245Wh/day ≈ 68 days

> Without any energy harvesting, the node can operate for roughly **2 months** on a full charge under the assumed duty cycle.

With Airflow Power Harvesting

The node uses a small turbine (dynamo) to convert duct airflow into electrical energy.
Power generation depends heavily on airflow velocity and turbine diameter.

Rotor Diameter	Air Speed	Theoretical Power	Practical Electrical Output	Status
50 mm	2.5 m/s	3.7 mW	~3–9 mW	❌ Insufficient
50 mm	5 m/s	29 mW	**~15 mW**	✅ Marginally Self-Powered
50 mm	10 m/s	236 mW	~120 mW	✅ Surplus Power
100 mm	5 m/s	118 mW	~60 mW	✅ Comfortable Margin

Node Power Need: ~10.2 mW
Harvest Target: ≥10.2 mW average for sustained operation

> At 5 m/s airflow, a 50mm turbine can roughly match the node’s power needs.
> With 100mm or higher airflow speed, the system can run **indefinitely** while charging the battery.

Summary

Mode	Avg. Power	Energy Source	Expected Runtime
Battery Only	10.2 mW	3.7V 4500mAh	~68 days
With Harvest (5 m/s, 50mm rotor)	10.2 mW load / ~15 mW harvest	Airflow + Battery	Indefinite
With Harvest (Low Airflow ❤️ m/s)	<10 mW harvest	Airflow + Battery	Partial support, shorter runtime

> With a 4500mAh battery, the node can last about **2 months** without airflow.
> In active ducts (≥5 m/s airflow), the **harvested energy can fully sustain** the system indefinitely.

Gateway (nRF7002 dev kit)

- **Powering:** The gateway uses an **nRF7002 dev kit** and is powered via an **external adapter** (mains). Hence we will **not** include the gateway in the battery runtime calculations.

Create a detailed Bill of Materials for the physical elements of your product

Hardware and Software BOM

Financial Model

Complete your product's financial model, including a pricing strategy and sale price

Product Financial Model & Pricing Strategy

This section outlines our HVAC monitoring ecosystem's financial model, including the **sensor node**, **inspection robot**, and **dashboard platform**. The goal is to balance **hardware margins** with **recurring revenue** from rentals and subscriptions.

1. Sensor Node

Item	Cost per Unit
Components + Mechanical Parts	$130
Assembly, Testing & QA	$15
Logistics & Shipping	$10
Insurance (transport + field warranty)	$5
Total Manufacturing Cost	**$160**

Tiered Selling Price

Order Size	Selling Price per Unit
1–10 units	$260
11–50 units	$255
51–100 units	$250
100+ units	$240

Notes:

- Covers insurance, assembly, testing, shipping, and support.
- Tiered pricing encourages larger orders while maintaining margins.
- Margin target: ~40%.

2. Gateway (nRF7200 Dev Kit)

Item	Cost
nRF7200 Dev Kit	$100
Protective Case	$20
Power Adapter	$15
Total Cost	**$135**
Selling Price	**$200**

Notes:

- Gateway is mains-powered via adapter; we do **not include battery costs**.
- Could be sold as a one-time purchase with sensor nodes or included in enterprise packages.
- Margin can be ~40–50% depending on bundle pricing.

3. Inspection Robot

Parameter	Estimate
Full Cost (Current Version)	Bought of the shelf just for demo
Rental Model	$100–200 per day, depending on service package
Future Plan	In-house development to reduce cost to ~$8,000–12,000 per unit depending on add ons

Notes:

- Rental supports short-term HVAC inspection contracts.
- Ideal for maintenance companies or pilot deployments.
- In-house production will allow sale or lease options in the future.
- Large companies could buy the complete bot.

4. Dashboard & Analytics Platform

Subscription Pricing (per month)

Tier	Features	Monthly Price
Standard	Real-time monitoring, OTA updates, baseline security	$15
Advanced	Analytics, reports, predictive insights	$30

Notes:

- Standard tier ensures device security and basic monitoring.
- Advanced tier generates recurring revenue via analytics.
- Enterprise or volume accounts can receive custom pricing.

Summary

Component	Cost	Selling / Rental Price	Revenue Model
Sensor Node	$150	$220–$250 (tiered)	One-time sale
Gateway	$135	$180–$200 (suggested)	One-time sale / bundle
Inspection Robot	$10,000	$150–250/day	Rental
Dashboard	—	$10–25/month	Subscription

Goal:
Maintain a ~30 - 40% gross margin on hardware, while generating recurring revenue from **dashboard subscriptions** and **robot rentals**. Over time, reducing hardware costs and increasing analytics adoption will improve overall profitability.

Example: Family Sizes — Total Cost, Sale Price & Profit

Family Size (Sensor Nodes)	Gateways Needed	Total Manufacturing Cost	Total Sale Price	Total Profit	Average Profit Margin
1	1	$150×1 + $135×1 = $285	$260 + $200 = $460	$175	38%
5	1	$150×5 + $135×1 = $885	$260×5 + $200 = $1,500	$615	41%
10	1	$150×10 + $135×1 = $1,635	$260×10 + $200 = $2,800	$1,165	41%
20	2	$150×20 + $135×2 = $3,270	$255×20 + $400 = $5,500	$2,230	41%
50	5	$150×50 + $135×5 = $7,875	$255×50 + $1,000 = $13,750	$5,875	43%
100	10	$150×100 + $135×10 = $16,350	$250×100 + $2,000 = $27,000	$10,650	39%

Notes / Redundant Charges:

- Extra shipping or logistics beyond standard included costs
- Taxes or import duties
- Optional insurance, extended warranty, or installation fees