Craft Beer Monitoring: A Cyber-Physical IoT System for Precision Brewing

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LOBA® BUSINESS TO EXPERIENCE

Mobile Software Development Internship
(6 months)

2025

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BSc in Informatics & Computer Engineering

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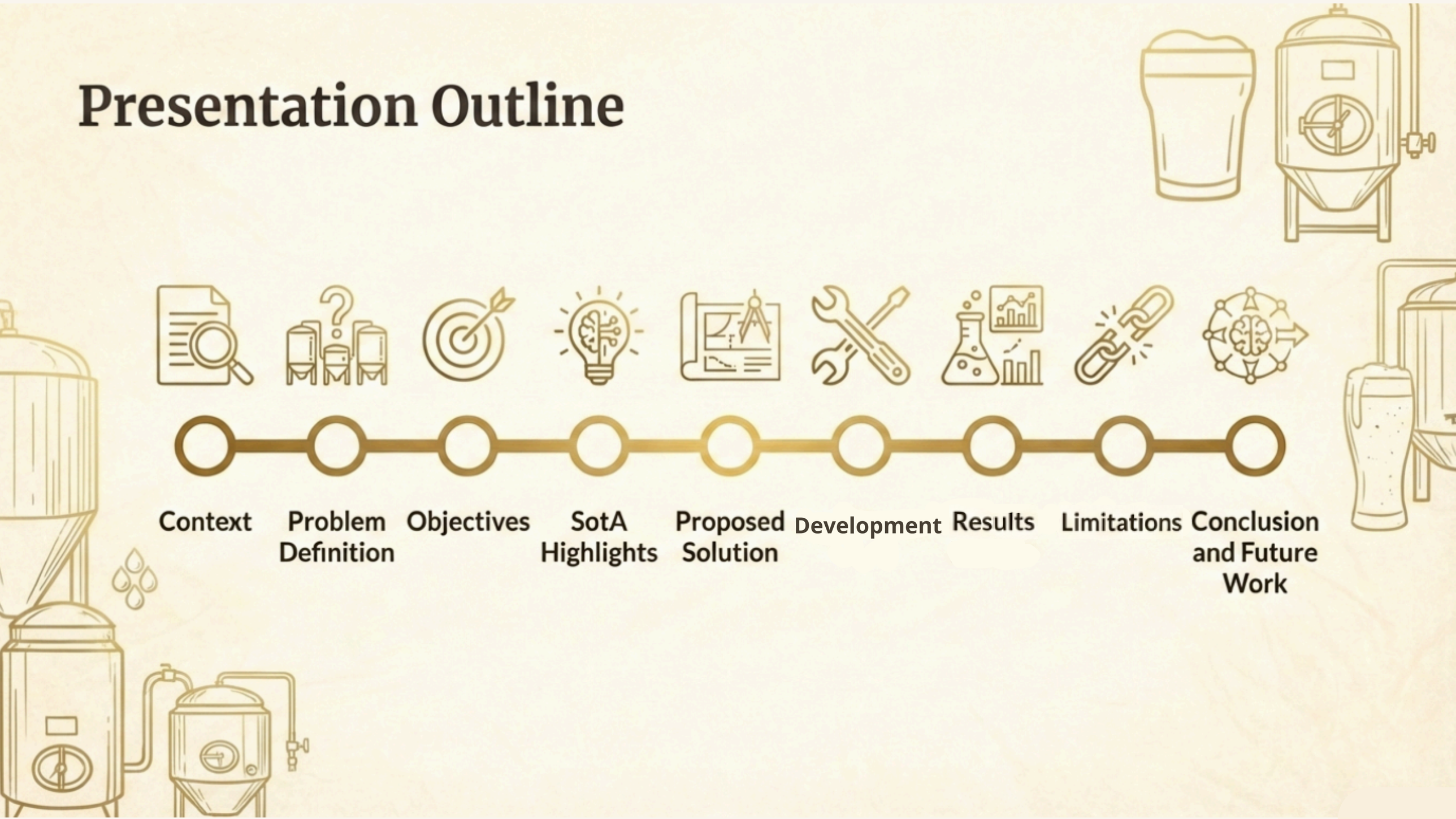
2026

INESC TEC

Research Grant
Agentic RAG Systems
(up to September 2026)

Presentation Outline



Context

Problem Definition

Objectives

SotA Highlights

Proposed Solution

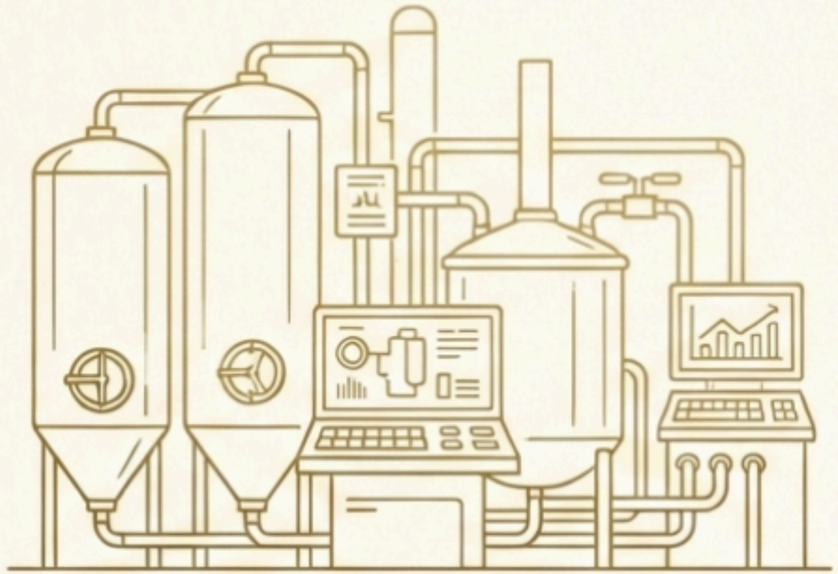
Development

Results

Limitations

Conclusion and Future Work

Context: Craft Beer Boom and Tecnology Gap



Industrial Conglomerates:
Automated SCADA Systems

SMEs & Homebrewers:
Manual, Offline Checks

While the craft beer segment has experienced explosive growth, small-scale producers lack access to the automated monitoring tools that ensure batch-to-batch consistency.

Problem Definition: The Fine Line Between Art and Waste

Fermentation happens inside closed vessels. Small, untracked fluctuations in invisible parameters lead directly to ruined art and wasted resources.

Temperature & pH

Critical drivers of yeast metabolism. Minor deviations can stall fermentation or alter flavor profiles.

Inconsistency

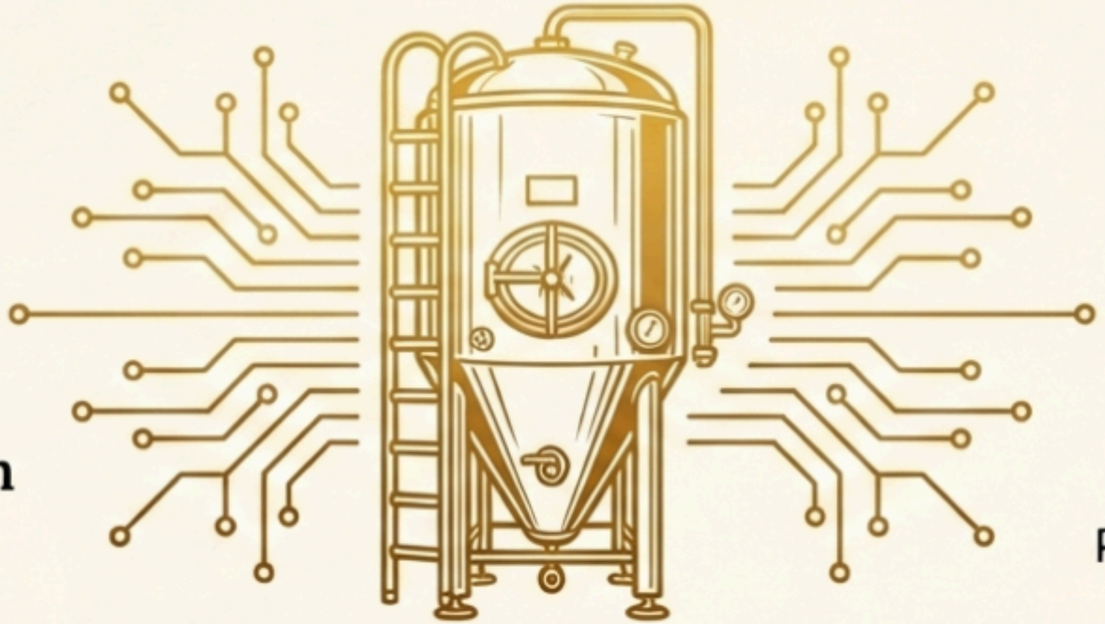
Error-prone manual checks miss vital metabolic changes.

Waste

Failed batches mean lost time, energy, and expensive raw ingredients.

Proposed Solution

Develop a low-cost, high-performance sensing ecosystem to democratize precision brewing.



Automated IoT System

Eliminate manual error by continuously tracking key parameters.

Real-time Control

Provide immediate data access via a simple mobile interface.

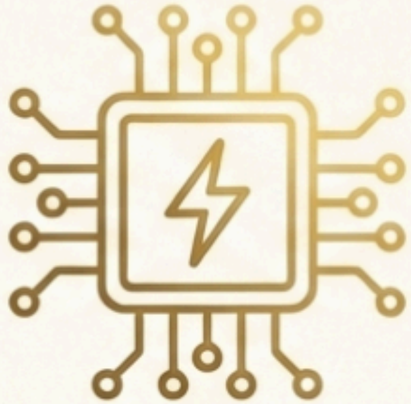
Proactive Alerts

Notify brewers of deviations before they become critical failures.

State of the Art Highlights

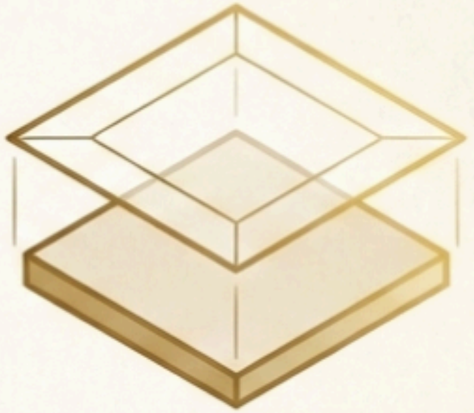
Winnie for Wineries

Modular IoT systems proved that low-cost commodity sensors can achieve high reliability for process optimization.



ESP32 Efficiency

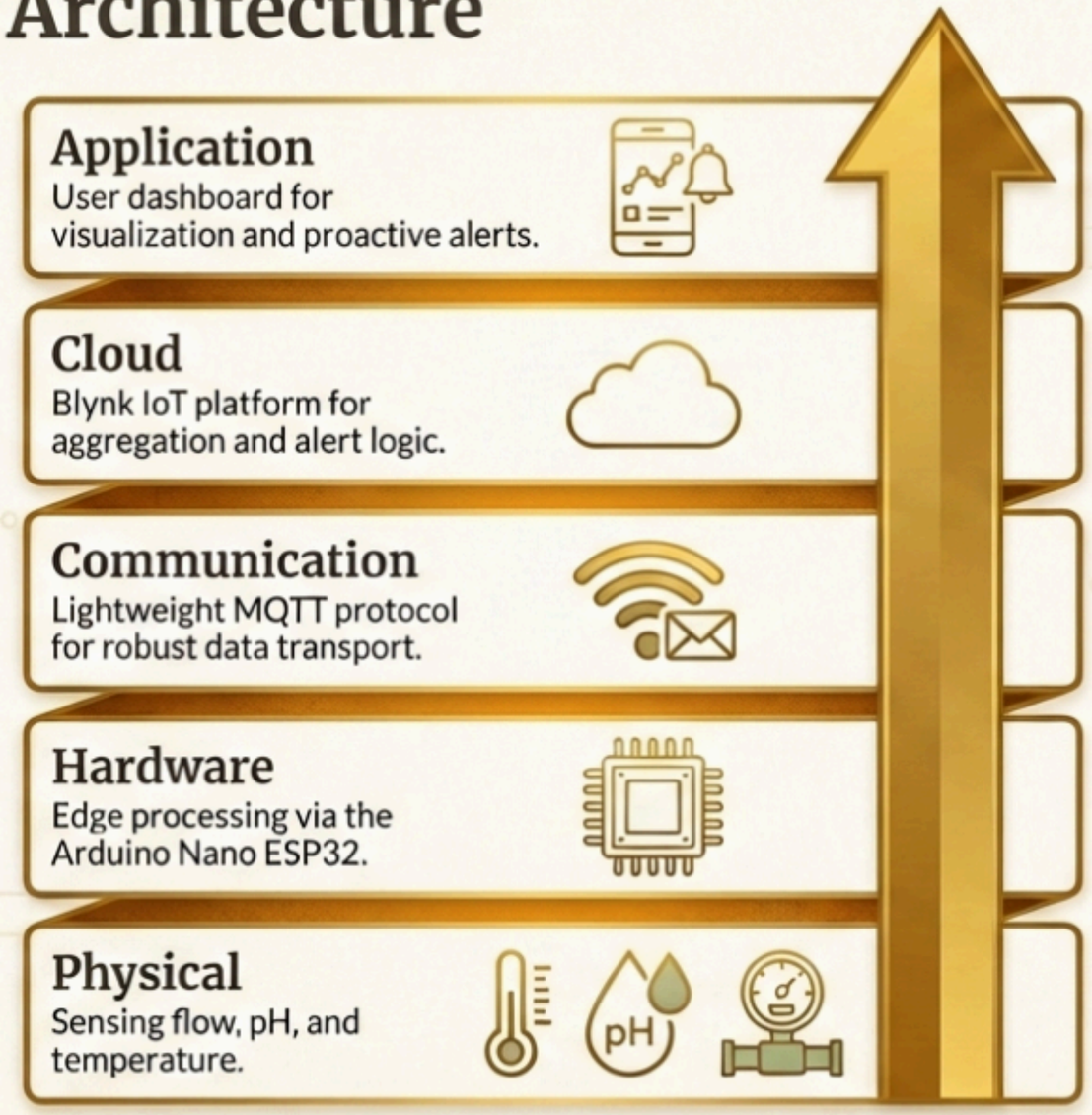
Demonstrated that deep-sleep modes allow continuous operation in resource-constrained, battery-powered environments.



Digital Twins

Shifting from reactive models to virtual replicas that safely explore “what-if” fermentation scenarios.

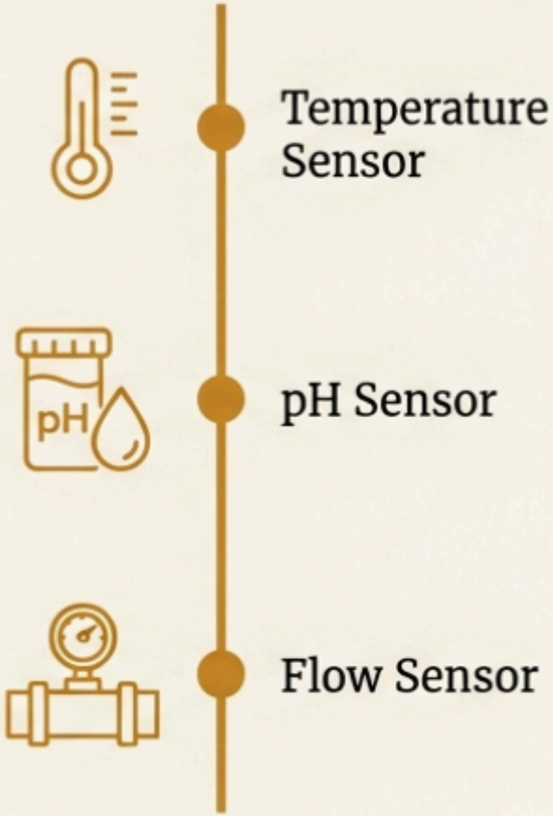
Proposed Solution Implementation: A 5-Layer Cyber-Physical Architecture



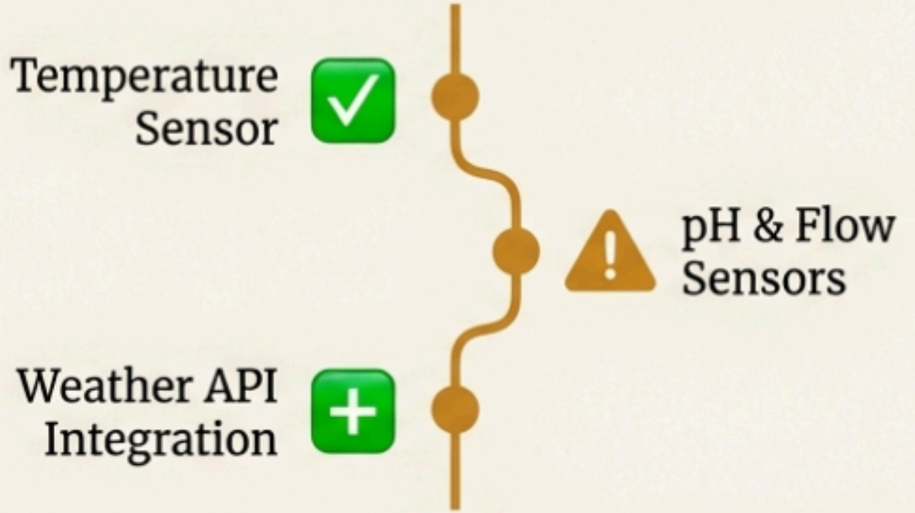
Implementation and the Strategic Pivot

The Arduino Nano ESP32 successfully established edge processing, but real-world hardware limitations required an agile engineering response.

Planned Proof of Concept



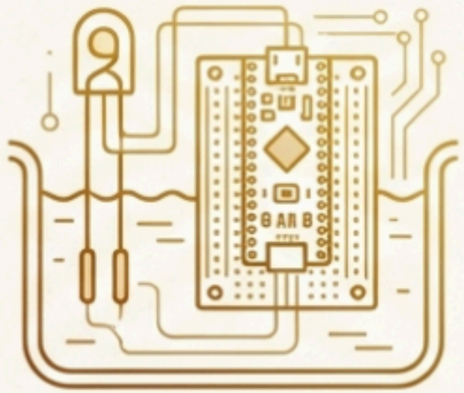
Realized Status & The Pivot



Hardware constraints with pH and Flow sensors forced a pivot to Software-in-the-Loop (SIL) data simulation to validate the cyber infrastructure.

Rigorous Testing: Physical Calibration and SIL Validation

Physical Calibration



- Waterproofed and submerged the KY-028 NTC thermistor in a controlled water bath.
- Applied the Steinhart-Hart equation directly within the edge firmware.
- Achieved consistent accuracy within ±1°C of reference analog thermometers.

Software-in-the-Loop

- Developed a Python-based simulation script mimicking non-linear yeast fermentation kinetics.
- Injected ‘Nominal’ data (standard bounds) to verify system stability.
- Injected ‘Critical' data (boundary-pushing states) directly into the cloud layer to stress-test the cyber infrastructure.

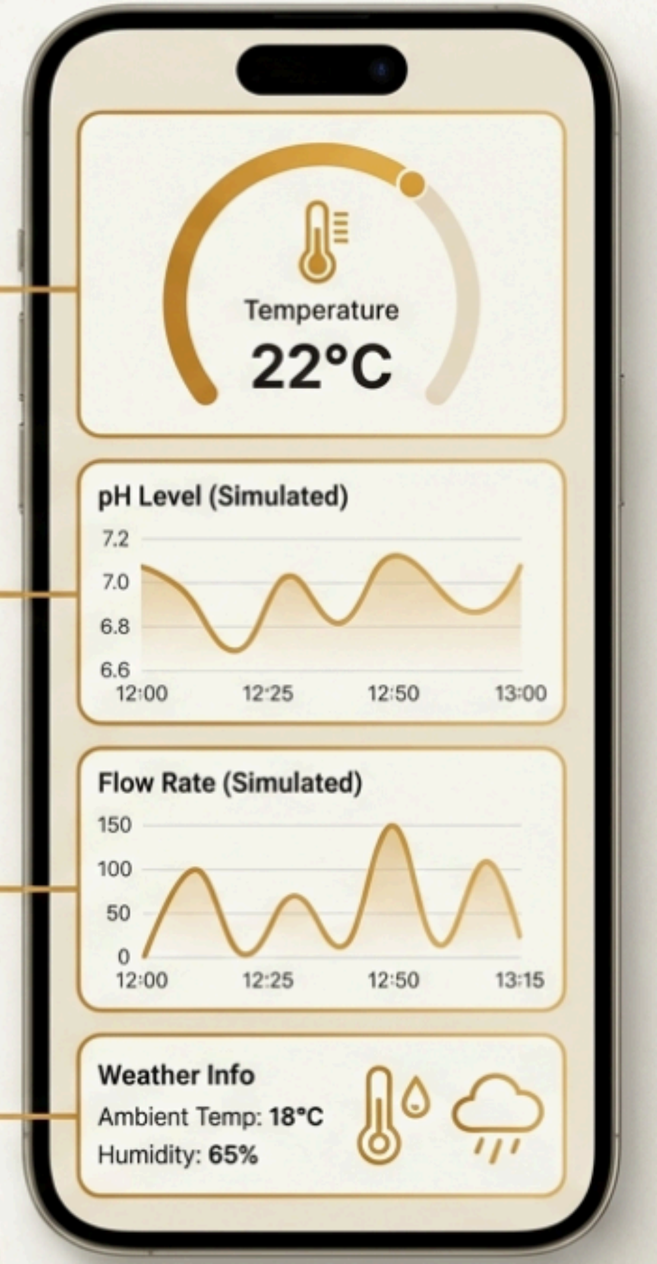
The Architecture Works: Real-Time Results

Logical Success

The cloud platform correctly identified out-of-bounds simulation data (e.g., Temp=105°C, pH=7) and instantly triggered high-priority mobile alerts.

Speed & Reliability

End-to-end MQTT communication latency averaged less than 200ms across 100 trials—exceptionally fast and robust for slow-moving biochemical processes.

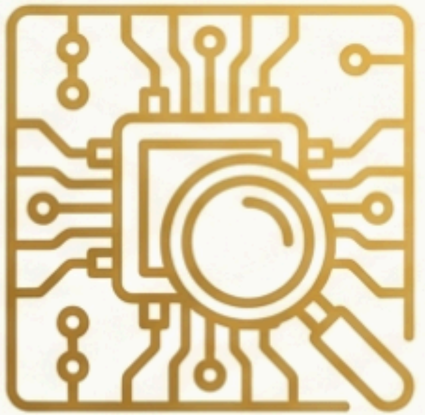


Navigating Real-World Limitations

Challenge 1: Material Unavailability

The lack of adequate and requested materials for key sensors directly impacted the project's timeline. This external factor forced a pragmatic adaptation of the project's physical scope, necessitating the SIL simulation pivot.

Challenge 2: Technical Hurdles

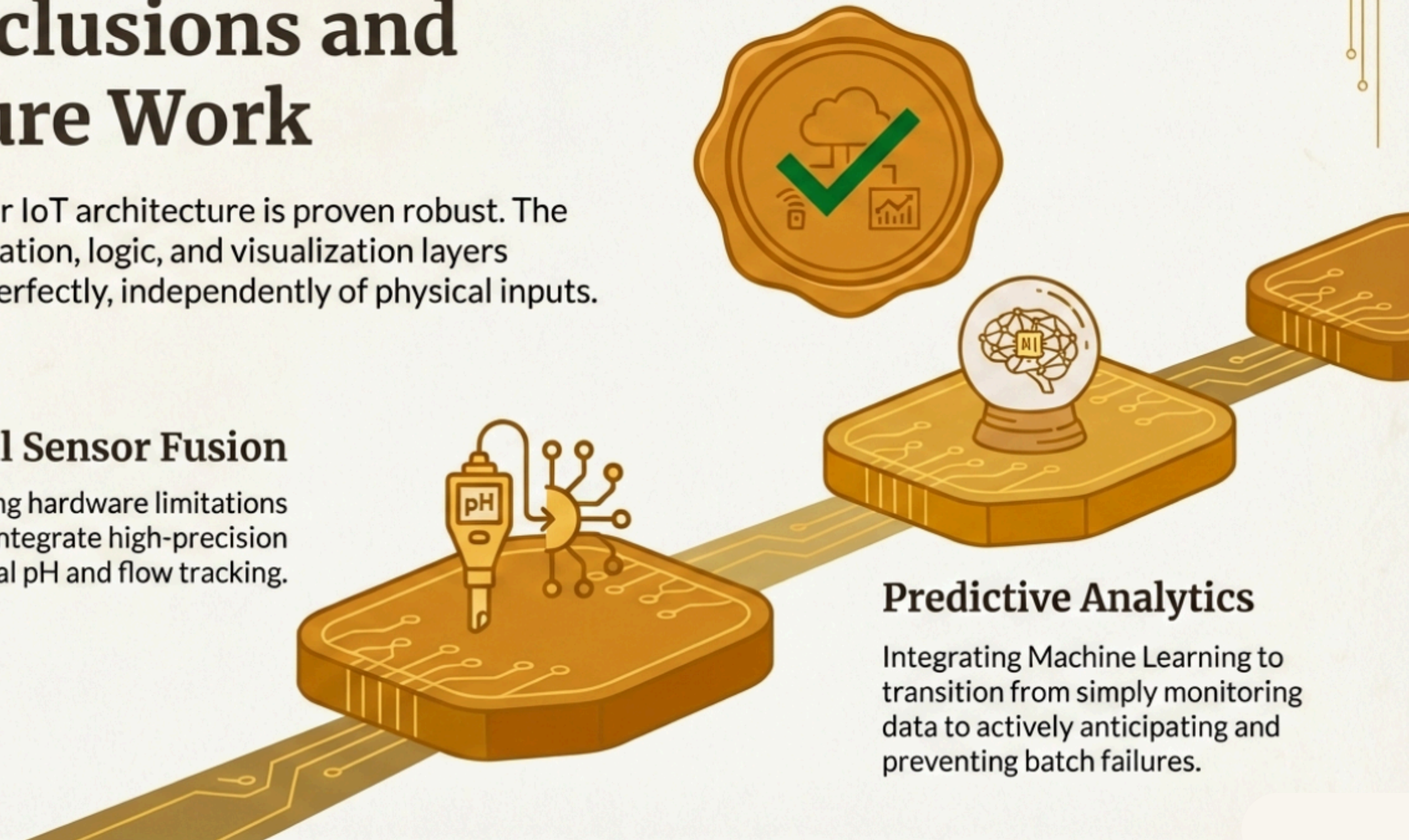


Integrating the available sensors with the ESP32 proved complex. A lack of deep background knowledge in electronics required extensive troubleshooting of the circuit integration, providing a steep but valuable learning experience.

Engineering is rarely a straight line; success lies in architectural adaptability.

Conclusions and Future Work

The 5-layer IoT architecture is proven robust. The communication, logic, and visualization layers function perfectly, independently of physical inputs.



Full Sensor Fusion

Resolving hardware limitations to integrate high-precision physical pH and flow tracking.

Predictive Analytics

Integrating Machine Learning to transition from simply monitoring data to actively anticipating and preventing batch failures.

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Thank You!

Any questions?

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