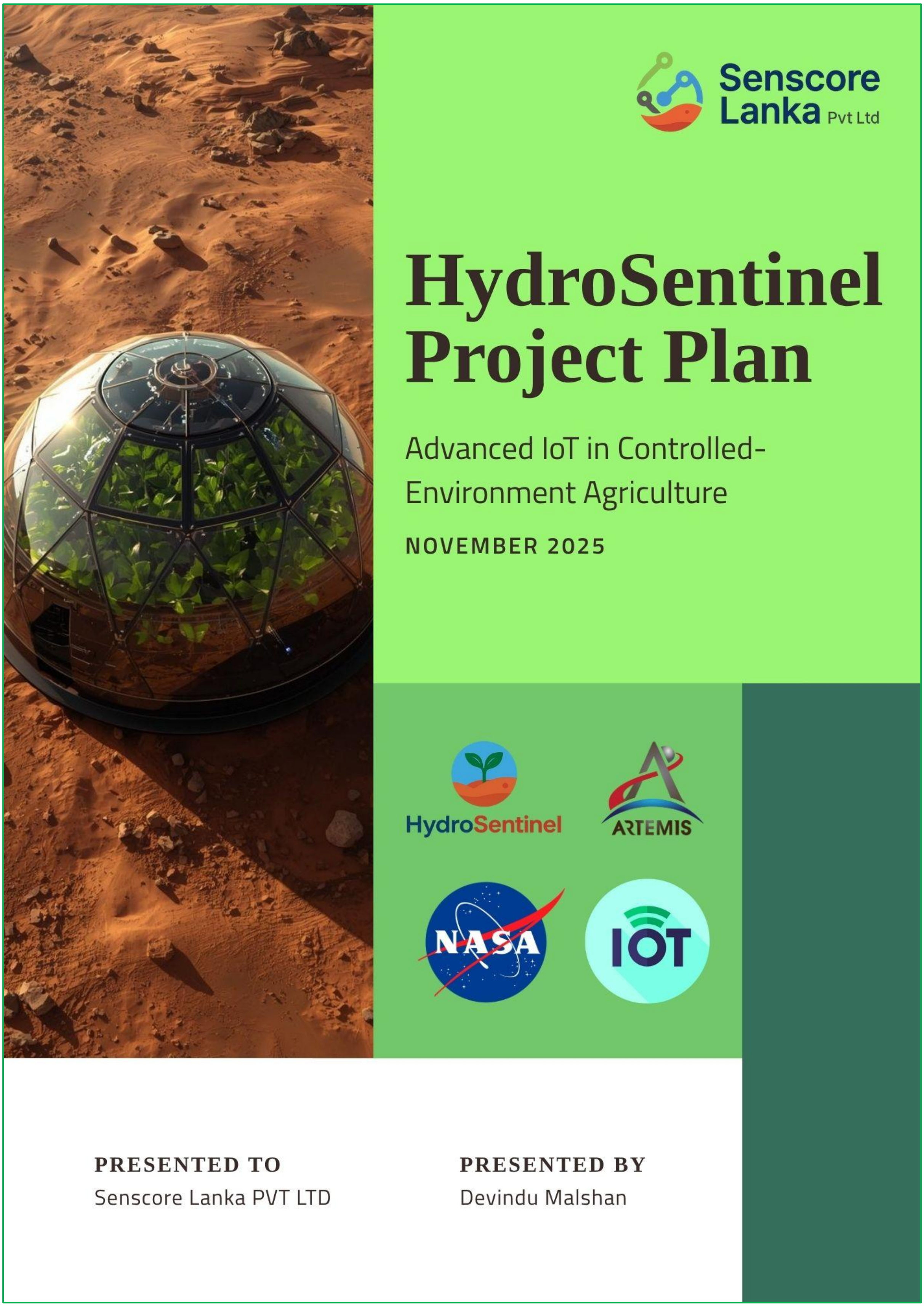

Senscore Lanka Pvt Ltd

HydroSentinel Project Plan

Advanced IoT in Controlled-Environment Agriculture

NOVEMBER 2025

HydroSentinel

ARTEMIS

NASA

IOT

PRESENTED TO
Senscore Lanka PVT LTD

PRESENTED BY
Devindu Malshan

Figure 1 HydroSentinel Project Plan Report Front Cover Page

PROJECT PLAN REPORT

HYDROSENTINEL: IOT SOIL MOISTURE MONITORING AND AUTOMATED IRRIGATION SYSTEM FOR CONTROLLED MARTIAN AGRICULTURE

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Date: 26 November 2025

INTRODUCTION

The HydroSentinel Project represents a futuristic application of Internet of Things (IoT) technology in controlled-environment agriculture, specifically conceptualized for NASA's Artemis colonization programme. As future missions envision establishing semi-autonomous habitats on Mars, food production within pressurized eco-domes will be a critical factor for human survival. This project focuses on building an intelligent, self-regulating irrigation system capable of maintaining soil moisture levels automatically, ensuring optimal crop growth in Martian farm domes where human labor and resources are limited.

HydroSentinel is designed to function as a real-time soil sensing and irrigation control system. It integrates a distributed network of soil moisture sensors connected to an ESP8266 microcontroller, transmitting data through Node-RED to a Blynk IoT cloud dashboard. When soil moisture levels drop below the configured threshold, the system autonomously activates a water pump through a relay module. A manual override option is available on the dashboard for direct control, while all data readings and system states are logged in real time for long-term crop optimization.

The HydroSentinel system also demonstrates how IoT AFTHA components of Architecture, Frameworks, Tools, Hardware, and APIs can be integrated to create scalable, energy-efficient, and autonomous smart farming systems. Although designed for a Mars mission scenario, the same concept applies to Earth-based agriculture, particularly precision irrigation in greenhouses and hydroponic farms.

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1. Problem Identification, Organizational Context, and Project Scope

1.1. Problem Definition

Humanity's next frontier of sustainable life beyond Earth which requires a radical rethinking of agriculture. The ability to grow food on Mars is not just a scientific experiment but a prerequisite for long-term colonization and mission self-sufficiency. However, cultivating crops in Martian regolith, even within pressurized bio-domes, presents unprecedented challenges.

The key limiting factors are:

- **Restricted water availability**: Every drop is a valuable resource transported or extracted at immense energy cost.
- **Limited human supervision**: Astronauts operate under strict schedules and cannot spend continuous time monitoring soil and irrigation.
- **Unpredictable soil behavior**: Martian soil differs chemically and physically from Earth's, demanding highly accurate moisture calibration and controlled hydration cycles.
- **Closed-loop ecosystem requirements**: The system must operate autonomously to recycle and conserve resources within the bio-dome.

Inconsistent irrigation in such an environment leads to either water wastage or plant dehydration both catastrophic in a resource-scarce extraterrestrial habitat.

HydroSentinel directly addresses this problem by developing an IoT-enabled, real-time soil moisture monitoring and pump control system capable of maintaining optimal soil hydration autonomously. It relies on a distributed network of capacitive moisture sensors, edge computing for decision-making, and cloud integration for remote supervision and analytics.

The prototype begins with potato cultivation, a crop chosen for its resilience, high nutritional value, and adaptability. Potatoes require precise soil moisture regulation & excess moisture leads to rot, while deficiency halts tuber formation. Achieving balance is crucial, making it the perfect test crop for Martian agriculture trials. Successful deployment with potatoes will serve as the foundation for expanding to other crops such as lettuce, beans, or wheat in future phases of the mission.

This concept not only simulates Martian agro-sustainability but also mirrors similar irrigation challenges on Earth, such as those in remote deserts, greenhouses, or water-scarce agricultural regions where automation and precision are vital.

1.2. Organizational Context

The HydroSentinel project is proposed as part of NASA's Artemis colonization programme, which envisions sustainable human presence on the Moon and Mars. Within this ecosystem, HydroSentinel functions as a core subsystem of the agricultural module, supporting the eco-dome cultivation framework. Its mission is to maintain soil health and ensure food reliability without constant human monitoring.

To align with real-world industry practices, HydroSentinel's design also parallels smart agriculture systems on Earth, bridging the gap between space research and terrestrial innovation.

Comparable real-world implementations include:

- **John Deere's Precision Agriculture Systems**, which combine IoT soil sensors, GPS data, and cloud analytics to optimize irrigation and resource management.

Figure 2 John Deere's Precision Agriculture Systems

- **Arable Labs' Mark 3 Devices**, which capture soil, light, and weather parameters for intelligent watering decisions.

Figure 3 Arable Lab's Mark 3 Device

- **NASA's VEGGIE experiment** aboard the ISS, which uses moisture sensors, LED lighting, and automated irrigation to sustain plants in microgravity environments.

Figure 4 NASA ISS Veggie Experiments

By synthesizing these principles, HydroSentinel acts as a research-driven testbed demonstrating how IoT AFTHA techniques of Architecture, Frameworks, Tools, Hardware, and APIs can enable intelligent, self-regulating agriculture in both Earth and extraterrestrial environments.

1.3. Project Overview and Scope

HydroSentinel aims to design, prototype, and test an IoT-based irrigation control system that autonomously manages soil moisture using real-time telemetry and intelligent actuation. The project focuses on small-scale implementation with scalability potential for larger applications.

Scope Includes:

1. **Soil Moisture Sensing** using resistive sensors to detect and transmit data continuously.
2. **Edge Computing Logic** on an ESP8266 NodeMCU for localized decision-making.
3. **Cloud Integration** via Node-RED and Blynk for real-time visualization and manual override.
4. **Automated Pump Activation** through a relay-controlled DC pump based on adaptive thresholds.
5. **Data Logging and Analytics** for performance monitoring and long-term optimization.

Scope Excludes:

- Nutrient composition sensing or pH regulation (to be added in future upgrades).
- External weather data integration or AI prediction (planned for later stages).
- Multi-crop calibration beyond potato-specific soil conditions at this phase.

The system's modular design allows future integration with AI-based irrigation forecasting, machine learning analytics, and multi-sensor networks for complete environmental control.

1.4. Project Goals and Objectives

Table 1 HydroSentinel Project Goals & Objectives

Goal	Objective
Enable sustainable, autonomous irrigation on Mars and Earth	Develop a real-time soil moisture sensing and irrigation system using IoT AFTHA components.

Optimize water utilization	Integrate intelligent pump activation logic to prevent over/under-irrigation.
Ensure reliability in low-supervision environments	Employ edge computing for local decision-making with cloud-based monitoring.
Provide transparency and remote control	Implement Blynk dashboards and Node-RED logic for remote access.
Build a scalable and low-cost model	Use open-source tools, affordable hardware, and reusable frameworks.

These objectives are strategically aligned with NASA's long-term vision of creating self-sustaining agricultural ecosystems for interplanetary habitation.

1.5. Project Milestones and Deliverables

Table 2 Project Milestones & Deliverables

Phase	Milestone	Deliverables	Timeframe
Research & Planning	Define problem, collect requirements, identify AFTHA components.	Project proposal, requirement documentation.	Week 1 – 2
Design	Develop system architecture, wiring diagram, and flowchart.	IoT architecture schematic, dashboard mockup.	Week 3
Development	Program ESP8266 and integrate Blynk–Node-RED framework.	Firmware, Node-RED flow design, initial prototype.	Week 4 – 5
Testing	Test moisture thresholds and pump activation under controlled conditions.	Functional test logs, calibration report.	Week 6
Evaluation	Gather feedback, assess performance and reliability.	User feedback report, performance metrics.	Week 7
Documentation & Presentation	Prepare development report and demonstration materials.	Final project report, presentation slides, prototype video.	Week 8

2. Investigation of AFTHA Techniques for Project HydroSentinel

The HydroSentinel system relies on the structured and strategic integration of IoT Architecture, Frameworks, Tools, Hardware, and APIs to achieve reliable soil moisture monitoring and automated irrigation. This section presents an in-depth investigation of the AFTHA components that underpin the project, supported by industry parallels and evidence of why each technique is appropriate for a smart agriculture environment both on Earth and within a conceptual Martian eco-dome.

2.1. IoT Architecture

The system adopts a hybrid IoT architecture, combining edge computing for immediate decision-making and cloud connectivity for visualization, long-term analysis, and remote supervisory control. This architectural model is widely regarded as the most efficient and reliable for precision agriculture applications, especially those requiring resilience, autonomy, and minimal human intervention.

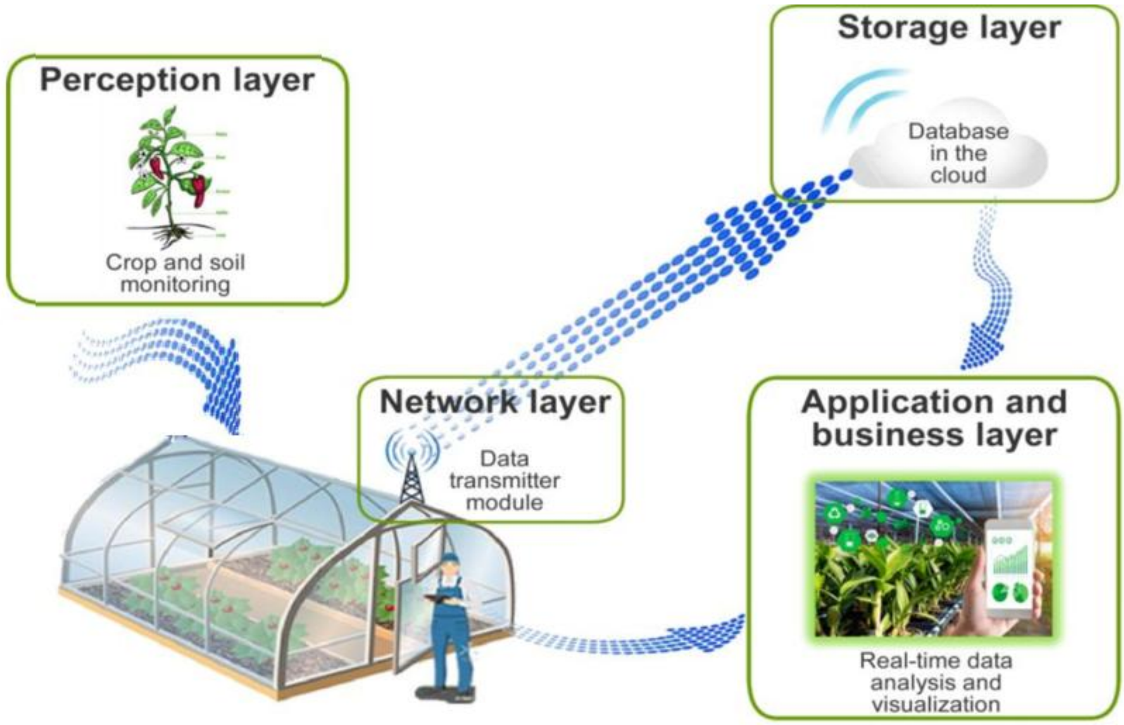


Figure 5 IoT Architecture for Project HydroSentinel

Perception Layer

The perception layer consists of resistive soil moisture sensors, which detect moisture levels by measuring variations in electrical resistance between two conductive probes inserted into the soil. As the soil becomes wetter, electrical conductivity increases; as it dries, resistance rises. These sensors provide continuous analog moisture readings in real time and form the core data acquisition mechanism of the HydroSentinel system.

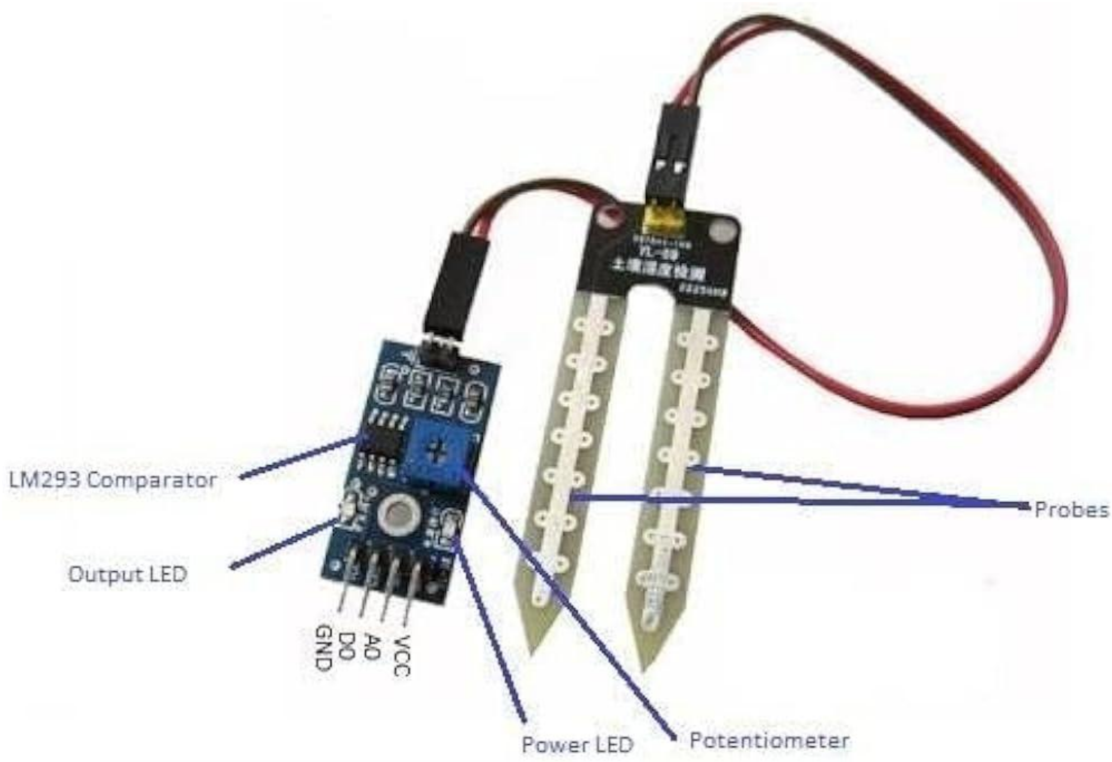


Figure 6 Resistive Soil Moisture Sensor

Edge Layer

At the edge layer, the ESP8266 NodeMCU microcontroller performs localized data processing, including smoothing noisy readings, applying threshold logic, and determining when irrigation should begin. Critical operations such as activating the relay-controlled pump are performed locally to ensure low latency and avoid dependence on constant cloud connectivity.

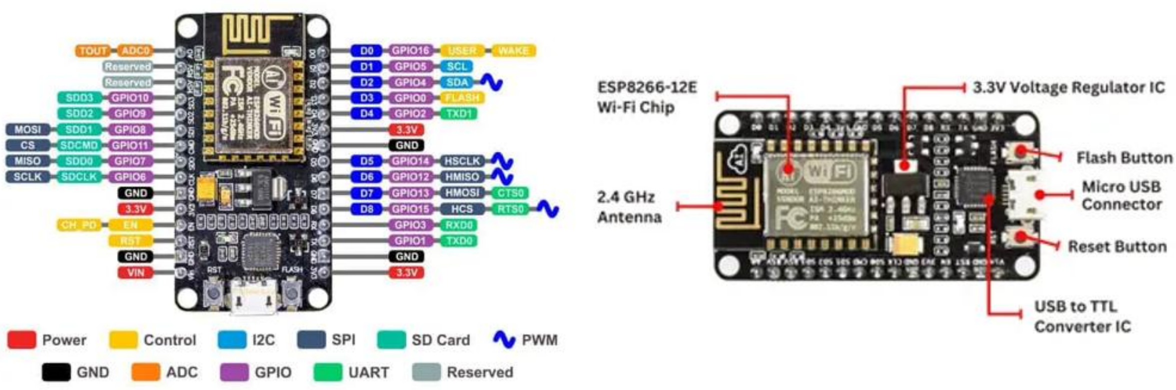


Figure 7 ESP8266 NodeMCU Microcontroller

This is essential for Martian agricultural systems, where intermittent communication delays or signal constraints may occur within habitat structures.

Cloud Integration Layer

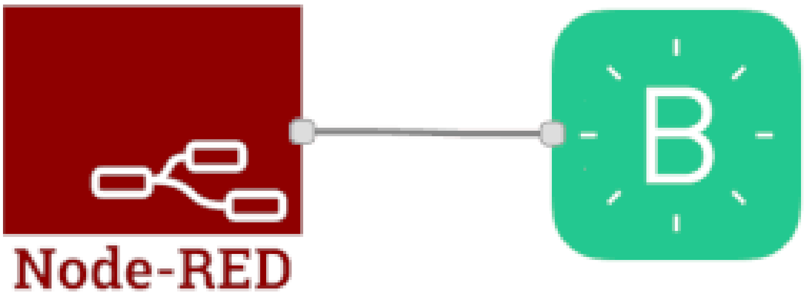


Figure 8 Node-Red & Blynk Cloud Integration

The cloud layer is responsible for advanced logic processing, automation orchestration, and user-facing interaction. Cloud services such as Node-RED provide rule-based processing (e.g., hysteresis, safety timers) and event logging. The Blynk Cloud platform serves as the central messaging hub that synchronizes telemetry between edge devices and dashboards.

This hybrid structure mirrors the architectures adopted by leading agricultural IoT solutions:

- ✓ **Bosch Deepfield Agriculture** uses distributed edge sensors with cloud analytics to determine water and nutrient requirements.
- ✓ **IBM Watson Decision Platform for Agriculture** combines in-field data ingestion with cloud-based AI that supports irrigation forecasting.
- ✓ **John Deere Operations Centre** integrates sensor data, GPS mapping, and cloud insights to optimize water distribution.

These real-world systems validate the suitability of the HydroSentinel architecture for both Earth-based and Mars-based applications.

Application Layer

The application layer provides users like astronauts, greenhouse operators, or farm technicians with intuitive access to real-time dashboards. Through Blynk's mobile and web interfaces, they can monitor soil moisture, manually override pump activation, and adjust moisture thresholds. This allows both autonomous and supervised operational modes, ensuring reliability under diverse mission conditions.

2.2. Frameworks

HydroSentinel integrates lightweight but powerful frameworks that support firmware management, logic processing, cloud connectivity, and user interface development. These frameworks enable rapid prototyping while remaining scalable for long-term smart farming deployments.

Firmware Framework: Arduino Core (ESP8266)

The system uses Arduino Core for ESP8266, a widely adopted firmware development framework providing seamless support for sensor interfacing, relay control, ADC operations, and Wi-Fi connectivity. Its simplicity, extensive library support (including the Blynk library), and stable toolchain justify its selection for both prototype and production-level IoT systems.

Logic and Integration Framework: Node-RED

Node-RED, a flow-based visual programming framework developed by IBM, is used for implementing advanced decision logic. It enables:

- Real-time rule evaluation (thresholds, hysteresis).
- Safety automation such as pump maximum run-time limits.
- Multi-path data routing to dashboards, logs, and notifications.
- Event-driven processing with minimal coding.

Node-RED is used extensively in industrial IoT sectors, including greenhouses, factories, and energy management due to its drag-and-drop visual logic and ability to integrate hardware, cloud services, and APIs.

Dashboard Framework: Blynk IoT Platform

The **Blynk Cloud platform** provides user dashboards with graphs, gauges, switches, and real-time data feeds. It is chosen for:

- Low latency WebSocket communication
- Multi-device access (mobile + web)
- Auth-token based secure device pairing
- Ease of configuration without extensive UI development

For a mission-oriented environment like a Mars eco-dome, Blynk offers rapid visualization with minimal resource overhead.

Integration Framework: Blynk–Node-RED Ecosystem

Node-RED's blynk-iot nodes enable seamless integration between the ESP8266, Blynk Cloud, and backend logic flows. This framework combination allows each subsystem to specialize:

- ESP8266 handles reading + local action
- Node-RED handles automation
- Blynk handles visualization

This modular framework structure mirrors modern agricultural IoT platforms where distributed sensors feed into cloud dashboards for monitoring and analytics.

2.3. Tools

A robust development environment is necessary for prototyping, testing, debugging, and managing system iterations. HydroSentinel utilizes open-source and industry-grade tools for each stage of the SDLC.

Arduino IDE

Used for firmware development, compilation, and flashing the ESP8266. It also provides a serial monitor for real-time debugging during calibration and field testing.

Node-RED Editor

A browser-based tool for visually creating and deploying logic flows. It features debug nodes, inject nodes, and flow storage, aiding rapid development and iterative logic refinement.

Blynk IoT Dashboard Builder

The app/web interface allows configuration of gauges, LEDs, buttons, timers, event logs, and graphical widgets. This eliminates the need for custom front-end development during the prototype stage.

Calibration Instruments

A multimeter and calibration formulas in firmware help ensure accurate readings from soil moisture sensors under different soil conditions, improving reliability for extraterrestrial agriculture.

Version Control: GitHub

Provides a structured repository for maintaining code versions, Node-RED flows, dashboard configurations, and documentation. It supports traceability and aligns with professional DevOps practices.

2.4. Hardware

Hardware selection directly influences reliability, efficiency, and sustainability, especially under mission-critical agricultural scenarios.

Key Components & Justifications

Table 3 Hardware Components & Function

Component	Function	Rationale
ESP8266 NodeMCU	Sensor reading, Wi-Fi connectivity, local processing	Low power, low cost, built-in Wi-Fi, suitable for always-on IoT.
Resistive Soil Moisture Sensor	Real-time moisture detection	Corrosive, less lifespan, unstable readings compared to Capacitive sensors.
4-Channel Relay Module	Controls pump switching	Provides electrical isolation and safe operation.
Mini DC Pump	Delivers water based on automated logic	Efficient, lightweight, realistic for modular hydroponic/soil irrigation.
LED Indicators	Local feedback signals	Useful for debugging and field operation without dashboard access.
5V/12V Power Supply	Powers microcontroller and pump	Stable operation, shared ground architecture for reliability.

These hardware components were chosen for their affordability, durability, and suitability for both Earth-based greenhouse setups and conceptual Martian agriculture prototypes. Their modular nature allows easy maintenance and expansion.

2.5. APIs

APIs ensure communication, control, and data flow across the IoT ecosystem by enabling seamless interaction between firmware, logic engines, and dashboards.

Blynk Cloud API

Provides programmable virtual pin communication using WebSocket protocols. It supports:

- Real-time reading and writing of sensor data
- Mobile dashboard updates
- Command reception for manual overrides

The API's speed and reliability make it well suited for mission environments where immediate feedback is essential.

Node-RED Blynk Nodes

Allow Node-RED flows to receive real-time updates from sensors via Blynk and transmit processed commands back to the device. This acts as the middleware API bridge of the system.

ESP8266 WiFiClient and Analog API

Enables:

- TCP/IP data transmission
- Analog input reading
- Local computation prior to cloud update

These APIs ensure lightweight, energy-efficient firmware execution.

Future API Integrations

The HydroSentinel system is intentionally designed with extensibility in mind, allowing future integration with external data services to enhance predictive intelligence and operational autonomy. As the project evolves, the system may incorporate NASA Mars Climate Data APIs to analyze simulated extraterrestrial environmental conditions such as atmospheric humidity, temperature fluctuations, and pressure variations within Martian habitats. This would enable more accurate modelling of water behaviour in treated Martian regolith and allow the irrigation logic to adapt dynamically to dome-wide climate shifts.

For Earth-based deployment, the system could integrate the OpenWeatherMap API, supplying real-time weather information such as rainfall forecasts, humidity trends, and evapotranspiration indicators to optimize irrigation cycles in smart greenhouses or open-field farms. These integrations pave the way for AI-driven irrigation schedules, where machine learning models use combined sensor data and climate patterns to predict crop water needs, reduce waste, and improve long-term sustainability.

The investigation of AFTHA techniques for the HydroSentinel system demonstrates how a carefully aligned combination of architecture, frameworks, tools, hardware, and APIs enables reliable, autonomous, and scalable smart agriculture operations.

By adopting a hybrid IoT architecture combining edge processing on the ESP8266 with cloud orchestration via Node-RED and Blynk, the system ensures low-latency irrigation control while still supporting remote supervision and analytics. The selected frameworks and tools create a cohesive development workflow that simplifies firmware programming, rule-based logic implementation, and dashboard creation.

Hardware components such as the resistive soil moisture sensor, relay module, and DC pump provide an affordable yet functional platform for real-time soil hydration management. Meanwhile, APIs form the communication backbone that links firmware, cloud services, and user applications into a unified ecosystem. Together, these AFTHA techniques establish HydroSentinel as a robust prototype capable of supporting both Earth-based precision agriculture and conceptual Martian eco-dome farming, laying the foundation for future enhancements in AI-driven irrigation and environmental automation.

3. Justification of AFTHA Techniques Selection for Project HydroSentinel

The planning and justification of the HydroSentinel system's Architecture, Frameworks, Tools, Hardware, and APIs (AFTHA) were carried out using structured engineering reasoning, project management principles, and alignment with both operational needs and budgetary constraints by the Senscore Lanka IoT engineer. As a smart-agriculture solution intended for controlled environments such as Martian eco-domes and Earth-based greenhouses, the chosen AFTHA components were evaluated based on technical feasibility, cost-effectiveness, energy efficiency, ease of integration, and long-term scalability. This section presents a comprehensive, project-plan–style justification for each selected component and the overall system strategy.

Architectural Justification

HydroSentinel adopts a **hybrid IoT architecture** integrating edge processing with cloud-based orchestration. This decision is grounded in the need for real-time responsiveness, operational autonomy, and continuous monitoring critical requirements for agriculture conducted in isolated planetary habitats where human supervision is limited. At the edge layer, the ESP8266 microcontroller processes moisture data and makes immediate irrigation decisions, ensuring that pump activation is not dependent on external network conditions. This reduces latency, improves reliability, and safeguards against communication outages.

The cloud layer, implemented through Blynk and Node-RED, provides remote supervision, advanced logic evaluation, data logging, alerting, and dashboard visualization. This dual-layer structure mirrors modern precision agriculture architectures adopted by major industry leaders such as John Deere Operations Center and IBM Watson Decision Platform for Agriculture, which combine local sensor intelligence with cloud analytics to improve crop management efficiency at scale. For HydroSentinel, the hybrid model provides an optimal balance between autonomy and oversight, allowing astronauts or greenhouse operators to monitor and override system behaviour from remote interfaces while ensuring the farm ecosystem continues functioning independently.

Framework Justification

The selected frameworks are designed to deliver a cohesive and interoperable software environment across firmware, logic orchestration, and user interaction. The **Arduino Core for ESP8266** framework was chosen for firmware development due to its extensive library ecosystem, simplicity, and reliability in handling analog inputs, Wi-Fi connectivity, and real-time sensor polling. For logic and data orchestration, **Node-RED** offers a visual flow-based programming interface that supports hysteresis implementation, safety timing rules, and event-driven behaviour without requiring complex custom software. This drastically accelerates development times and promotes iterative testing.

For user interaction, the project employs the **Blynk IoT platform**, which supports real-time dashboards accessible via both mobile and web interfaces. Blynk allows widgets such as gauges, sliders, logs, timers, and LED indicators to bind directly to virtual pins, enabling flexible configuration without user-side coding. Together, Arduino, Node-RED, and Blynk form a complete end-to-end development pipeline from sensor firmware to cloud intelligence to user dashboards while remaining cost-effective and scalable. This synergy ensures that HydroSentinel can evolve from a prototype to a fully deployable multi-sensor agricultural platform.

Tool Selection and Justification

The toolchain selected for HydroSentinel supports efficient development, structured testing, ongoing maintenance, and version control. **Arduino IDE** facilitates rapid firmware prototyping, serial debugging, and code uploads to the ESP8266. Its simplicity is ideal for early-stage development, while its extensibility supports advanced libraries as the system grows. **Node-RED's browser-based editor** enables engineers to rapidly adjust automation logic, integrate new APIs, and monitor live data flows through debug nodes. This is particularly useful in iterative testing, where logic must be frequently adjusted based on environmental readings.

The **Blynk web and mobile dashboard editors** provide intuitive visual interfaces for real-time monitoring, manual overrides, trend graphs, and parameter adjustments. Calibration tools such as multimeters and sensor-mapping utilities were used to verify the accuracy of the resistive soil moisture sensor across different soil conditions. Finally, **GitHub** is employed for version control, enabling structured code management, rollbacks, and collaboration. This tool ecosystem supports the SDLC by facilitating planning, development, testing, deployment, and iteration.

Hardware Selection and Justification

The hardware components selected for HydroSentinel were chosen using a combination of functional requirements, environmental compatibility, energy efficiency, and cost constraints. The **ESP8266 NodeMCU** was chosen as the primary microcontroller due to its integrated Wi-Fi module, low power consumption, and sufficient processing capability for edge-based logic. Its affordability and compatibility with Arduino make it ideal for constrained research environments such as Martian eco-domes or rural greenhouses.

The **resistive soil moisture sensor** is although less durable than capacitive sensors—was selected based on its extremely low cost, simplicity, and availability. Because HydroSentinel is currently a **prototype-stage system**, the resistive sensor provides a practical balance between usability and budget constraints. Its direct analog output integrates seamlessly with the ESP8266's ADC, enabling immediate deployment without additional interface circuitry. While resistive sensors are prone to long-term corrosion, these drawbacks are acceptable in controlled environments such as indoor grow beds or simulated Martian regolith. Mitigation strategies include intermittent operation cycles, protective coatings, and periodic recalibration.

Figure 9 4 – Channel Relay Module & Mini 3 – 6V DC Pump

A **4 - channel relay module** was selected to safely switch the DC pump, ensuring electrical isolation and protecting the microcontroller from voltage spikes. A **mini 3 – 6V DC pump** provides adequate flow for soil hydration while remaining compact and energy-efficient.

LED indicators support local troubleshooting and interpretation, while jumper wires, a small PCB, and low-cost resistors enable durable prototyping. Collectively, the hardware configuration achieves functionality and reliability without exceeding budget constraints, making it suitable for repeated experimentation and future scale-up.

API Selection and Integration Justification

APIs form the communication backbone of HydroSentinel, linking sensor data, edge logic, cloud orchestration, and user dashboards. The **Blynk Cloud API** allows the ESP8266 to transmit telemetry and receive control signals through secure WebSocket channels using virtual pins. This enables real-time synchronisation of sensor readings, pump states, alerts, and user inputs. **Node-RED's Blynk integration nodes** provide bidirectional communication, allowing cloud logic to override or enhance local behaviour. The **ESP8266 WiFiClient API** ensures stable TCP/IP communication within the eco-dome's internal network or an Earth-based Wi-Fi system.

HydroSentinel is also designed for future extensibility. Future integrations may include the **NASA Mars Climate Data API**, enabling irrigation adjustments based on internal habitat environmental trends, and external APIs such as **OpenWeatherMap** for Earth-based greenhouses. In later development cycles, these APIs can serve as data sources for AI-driven irrigation prediction models. This forward-compatible API ecosystem ensures long-term scalability and adaptability of the HydroSentinel system.

Project Quality Plan (Quality Standards, QA, QC)

Quality assurance in HydroSentinel follows engineering best practices, academic research standards, and IoT system development guidelines. Quality standards were defined around sensor accuracy, reliable communication, safety of pump operation, and dashboard usability. Quality assurance activities included adherence to established IoT security practices, documented calibration procedures, standardized coding conventions, and flow-based logic validation in Node-RED. Quality control involved systematic prototyping tests, moisture reading validation, pump actuation timing checks, and dashboard verification. The QA/QC approach ensures that the final prototype is reliable, safe to operate, and aligned with project objectives.

Project Schedule

The HydroSentinel project follows a structured eight-week timeline aligned to the SDLC. A Gantt chart accompanies the project plan, with major phases including:

- Research and requirement gathering
- Architecture definition and AFTHA selection
- Firmware development

- Node-RED logic configuration
- Dashboard construction
- System integration and calibration
- Testing and validation
- Documentation and final demonstration

Each task includes defined start/end dates, dependencies, and milestones to track progress and ensure timely project completion.

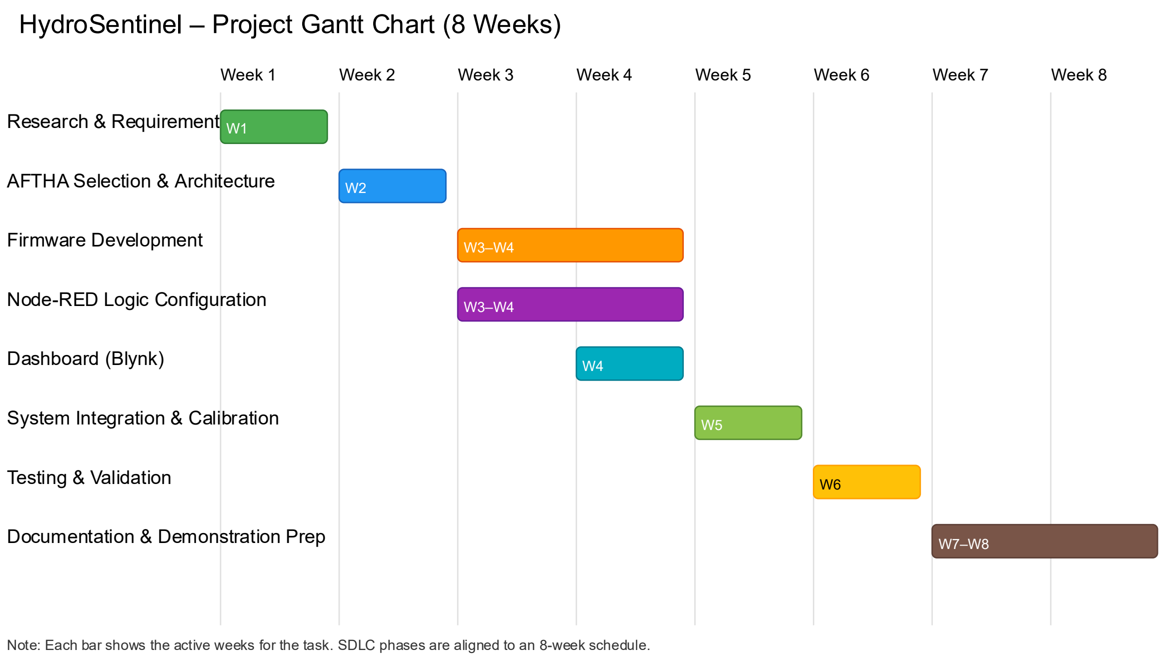


Figure 10 HydroSentinel Project Gantt Chart

The project begins with research and requirement gathering, establishing the operational constraints of Martian agriculture, the soil moisture thresholds relevant to potato cultivation, and the AFTHA components best suited for extraterrestrial deployment. This initial phase provides the foundation for all subsequent decisions.

Following this, architecture definition and AFTHA selection are carried out, detailing the hybrid edge–cloud design, the choice of ESP8266-based sensing, Node-RED logic orchestration, and Blynk cloud dashboard integration. This stage formally establishes the system blueprint and confirms component procurement.

Weeks three and four focus on firmware development for the ESP8266 and Node-RED logic configuration, where sensor reading routines, pump control logic, hysteresis, safety timers, and communication flows are implemented. Parallel work begins on dashboard construction, creating the Blynk interface for data visualization, threshold configuration, and manual overrides.

The latter half of the schedule emphasizes system integration and calibration, ensuring accurate moisture readings, mapping sensor outputs, validating relay switching, and synchronizing telemetry between devices, Blynk, and Node-RED. This phase ensures the physical and software systems work together seamlessly.

Once integrated, the system undergoes testing and validation, including functional testing, stress testing (extended pump cycles), threshold accuracy verification, and user experience evaluation via the dashboard interface. Identified issues are logged and resolved before final deployment.

The final stage includes documentation and preparation for demonstration, compiling the project report, capturing photographs of the prototype, preparing wiring diagrams, and finalizing the demonstration script for presentation.

Together, these planned activities ensure that HydroSentinel progresses through a disciplined engineering lifecycle, with measurable milestones and controlled iteration from concept to fully functional IoT irrigation prototype.

Resource Plan

The project requires both technical and material resources. Technical resources include the ESP8266 board, sensor equipment, power supplies, and computing hardware for running Node-RED. Human resources include the IoT engineer responsible for firmware development, flow construction, and dashboard configuration. Software resources include Arduino IDE, Node-RED, Blynk platform access, and GitHub for version control.

Procurement Management Plan

All components for HydroSentinel were procured from local electronic suppliers and online marketplaces based on availability (Daraz), cost, and delivery timelines. Procurement considerations focused on compatibility with the microcontroller, durability, and adherence to the project budget. Items were verified upon arrival for quality and functionality. The procurement process ensured minimal delays and efficient allocation of funds.

Project Budget and Cost Management Plan

Table 4 Project Budget & Costs

Component	Qty	Unit Price (LKR)
Soil Moisture Sensor (Resistive)	1	205
4-Channel Relay Module	1	850
Mini DC Water Pump	1	279
ESP8266 Wi-Fi Board	1	1,129
Jumper Wires (40 pcs)	1	406
Small PCB	1	140
Resistors	3	3
LEDs (R/G/B)	1 set	30
Delivery Costs	—	760

Total Estimated Cost: LKR 3,802

The system remains affordable, making it suitable for research environments, small farms, or educational deployment. Cost management involved selecting low-cost components without compromising essential performance.

Change Management Plan

A lightweight change control process was established to track firmware modifications, Node-RED logic updates, sensor calibration changes, and dashboard interface revisions. All changes were documented through GitHub commits, ensuring traceability and rollback capability. Proposed changes were evaluated for system impact, integration complexity, and alignment with project objectives before implementation.

Risk Management Plan

A structured risk management approach was adopted to identify, evaluate, and mitigate risks.

Risk Matrix

Table 5 Risk Matrix

Likelihood \ Impact	Low Impact	Medium Impact	High Impact
High Likelihood	—	**Sensor Degradation** (corrosion, drift over time) **Mitigation:** intermittent readings, protective coatings, periodic recalibration	—
Medium Likelihood	—	—	**Pump Overrun / Pump Failure** (risk of flooding, motor burn-out) **Mitigation:** Node-RED safety timers, edge-level cut-off logic, runtime limits
Low Likelihood	—	—	**Wi-Fi Connectivity Failure** (loss of cloud dashboard access) **Mitigation:** edge autonomy, offline local threshold control

The risk assessment for HydroSentinel identifies three priority concerns based on likelihood and impact. First, sensor degradation is classified as a high-likelihood but medium-impact risk because resistive soil moisture sensors naturally corrode over time, leading to reduced accuracy.

This is mitigated through intermittent operation, which reduces exposure to electrolysis, and protective coatings that slow oxidation and extend sensor lifespan. Second, pump overrun represents a medium-likelihood but high-impact risk, as uncontrolled pump activation can lead to soil flooding, water wastage, or pump motor damage. This is addressed through Node-RED safety timers, which strictly regulate pump runtime, and edge-level fail-safes, ensuring immediate shutdown under abnormal conditions.

Finally, Wi-Fi failure has a low likelihood but high potential impact because loss of cloud connectivity could disrupt remote monitoring. However, the system’s edge autonomy ensures that critical irrigation logic continues to run locally on the ESP8266, allowing soil hydration control to operate uninterrupted even without internet access.

Risk Log

A risk log was maintained throughout development, with periodic reviews to update mitigation measures.

Table 6 Risk Log

Risk	Likelihood	Impact	Risk Level	Mitigation Strategy
Sensor degradation	High	Medium	High	Protective coating, intermittent duty cycle, recalibration
Pump overrun	Medium	High	High	Node-RED safety timers, hard runtime limits, fail-safe logic
Wi-Fi failure	Low	High	Medium	Edge autonomy ensures continued irrigation offline
Power instability	Low	Medium	Low	Stable power supply, shared ground, voltage regulation
Soil contamination variability	Medium	Medium	Medium	Threshold tuning, data logging, calibration

This proactive strategy ensured that potential failures were managed before affecting system performance.

CONCLUSION

The HydroSentinel project plan brings together a pragmatic, well-justified design for an IoT-driven soil moisture monitoring and automated irrigation system tailored for controlled-environment agriculture. The plan demonstrates clear alignment between the problem definition (sustainable potato cultivation in pressurized Martian eco-domes and analogous Earth-based greenhouses) and the chosen AFTHA stack: a hybrid edge–cloud architecture, Arduino/ESP8266 firmware, Node-RED orchestration, and a Blynk dashboard for operator visibility and manual control. This integrated approach ensures that edge autonomy, cloud supervision, and human oversight are balanced to meet the mission constraints described in the project brief.

The SRS summary and SDLC mapping included in the plan provide strong evidentiary documentation for iterative development. Functional requirements (real-time sensing, automated pump control with hysteresis, manual override, logging, and offline autonomy) and non-functional requirements (reliability, low latency, safety timers, maintainability and scalability) are captured clearly and succinctly, giving implementers a precise checklist to follow during design, development, and testing. The iterative SDLC approach with defined planning, requirements, design, development, testing, deployment, and maintenance phases which creates a workflow that incorporates end-user feedback into each cycle, improving system robustness while controlling project risk.

Hardware, tool, and framework selections were made following cost, availability, and functional suitability criteria. Using the ESP8266 and resistive soil moisture sensors keeps the prototype low-cost and easy to iterate, while Node-RED and Blynk shorten development time and enable rapid, user-driven refinements. The project budget, procurement plan, and resource allocation demonstrate fiscal responsibility and practical feasibility for a research or classroom deployment. The included Gantt schedule and milestone plan give clear temporal structure to the eight-week prototype development and testing program.

Risk management and quality assurance have been integrated into the project plan. The risk matrix and mitigation strategies address the most significant operational vulnerabilities such as sensor degradation, pump overrun, and loss of connectivity by combining hardware protective measures, software safety timers, and architecture choices that favor edge autonomy. QA/QC practices (sensor calibration, logging, controlled tests) and a lightweight change-control process are described so the team can validate performance, maintain traceability, and apply corrective measures during iterative cycles. These governance components are essential for eventual transition from prototype to operational deployment.

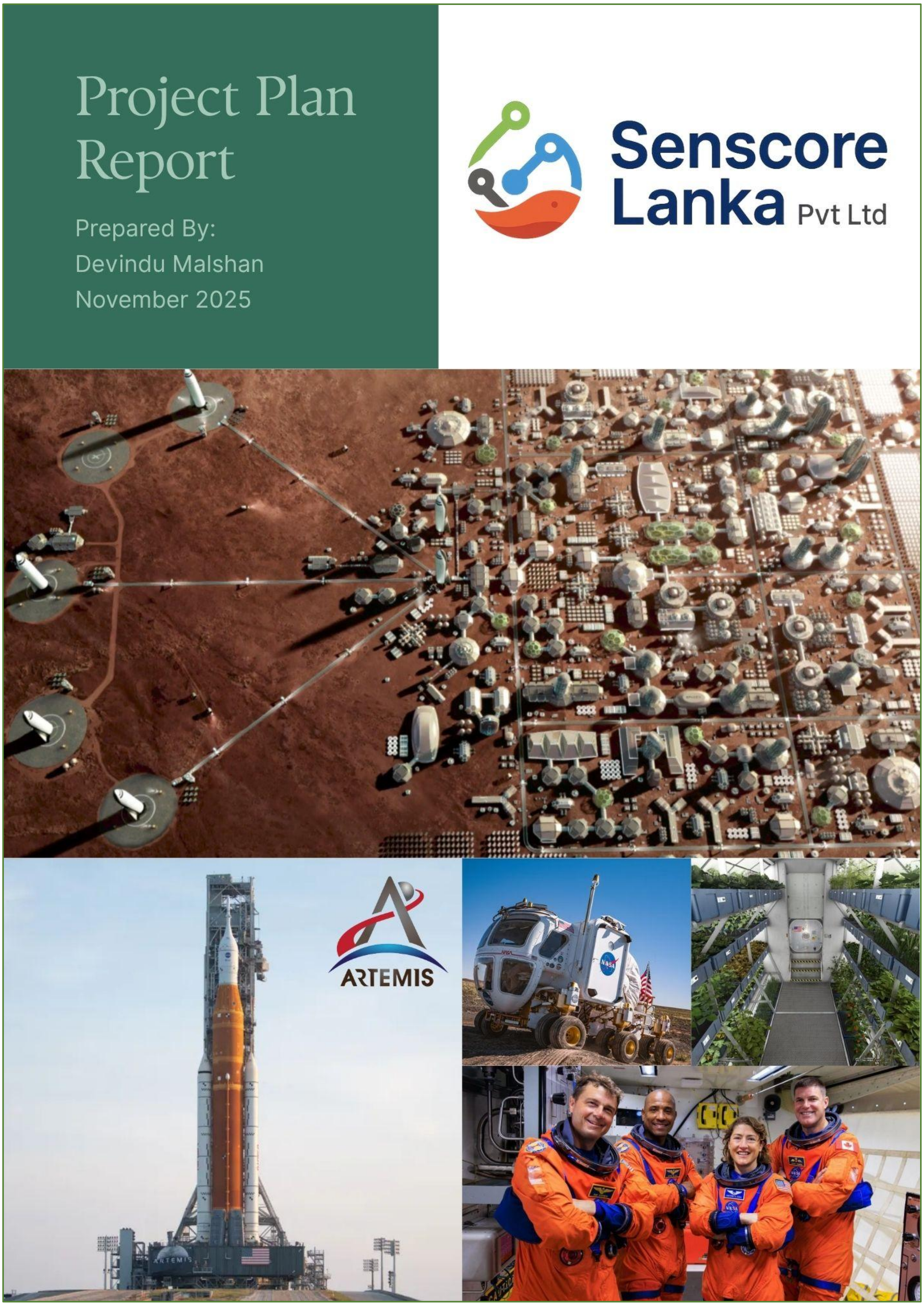
From an engineering and programmatic perspective, HydroSentinel's strongest asset is its modularity: each AFTHA layer is replaceable or upgradeable without redesigning the entire system. This design decision supports a clear roadmap of future enhancements:

(1) Replace resistive sensors with capacitive sensors for longer-term stability in later production builds;
(2) Extend the telemetry and analytics pipeline to include historical databases and ML models for predictive irrigation using climate or habitat data (e.g., NASA Mars environmental feeds or OpenWeatherMap for Earth scenarios);
(3) Expand to multi-zone control and multi-crop calibration;
(4) Add OTA firmware updates and stronger device authentication and encryption to meet regulatory and safety standards for human habitats.

These steps will increase reliability, reduce maintenance, and enable data-driven optimization of crop yields.

Operationally, the next immediate steps recommended are: complete the first prototype iteration and run controlled greenhouse trials that replicate Martian regolith conditions where possible; collect structured end-user feedback (usability, threshold behaviour, alerting); perform extended durability runs to quantify sensor drift and pump reliability; and then implement Iteration 2 improvements (sensor protection, safety-timer tuning, dashboard refinements). Concurrently, document compliance and interoperability considerations (medical/food safety if applied to crew food systems, IEEE/IEC IoT best practices, and data privacy policies) so the solution can scale into mission-critical contexts.

In summary, HydroSentinel presents a technically coherent and budget-conscious project plan that addresses the core challenge of autonomous irrigation in low-supervision, resource constrained environments. The report provides the necessary AFTHA rationale, SRS elements, SDLC plan, risk controls, and procurement details required for a credible prototype phase. With the recommended iterative validations, sensor upgrades, and augmentation of analytics capabilities, HydroSentinel is well positioned to evolve from a functional prototype into a resilient subsystem for controlled-environment agriculture, supporting both terrestrial precision farming and the long-term objectives of interplanetary habitation.



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