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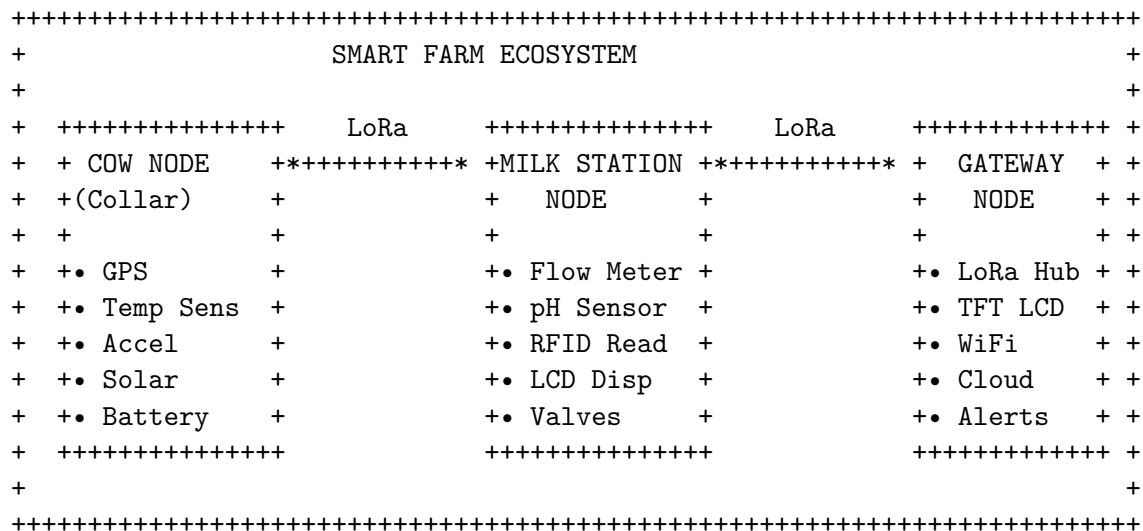
SMART FARM SYSTEM - TECHNICAL SPECIFICATIONS

Document Information

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1. SYSTEM OVERVIEW

1.1 Architecture Diagram



1.2 Communication Matrix

Source	Destination	Protocol	Frequency	Data Type
Cow Node	Gateway	LoRa 915MHz	Every 30s	Health data
Milk Station	Gateway	LoRa 915MHz	Per session	Production data
Gateway	Cloud	WiFi/4G HTTP	Every 5min	Aggregated data
Mobile App	Cloud	HTTPS	Real-time	User requests
Cloud	Gateway	WebSocket	Real-time	Alerts/Config

2. COW NODE SPECIFICATIONS

2.1 Hardware Specifications

2.1.1 Main Controller

- **Microcontroller:** ESP32-WROOM-32
- **Architecture:** Dual-core Xtensa LX6
- **Clock Speed:** 240 MHz
- **RAM:** 520 KB SRAM
- **Flash:** 4 MB
- **Wireless:** Wi-Fi 802.11 b/g/n + Bluetooth 4.2

2.1.2 Sensors

Sensor	Model	Interface	Accuracy	Range	Power
Temperature	DS18B20	1-Wire	$\pm 0.5^{\circ}\text{C}$	-55°C to $+125^{\circ}\text{C}$	1mA
Accelerometer	MPU6050	I2C	$\pm 1\%$	$\pm 2/4/8/16\text{g}$	3.5mA
GPS	NEO-6M/8M	UART	$\pm 3\text{m CEP}$	Global	25mA
Battery Monitor	INA219	I2C	$\pm 0.5\%$	0-26V	1mA

2.1.3 Communication

- **LoRa Module:** SX1276/RFM95W
- **Frequency:** 915 MHz (US), 868 MHz (EU)
- **TX Power:** +20 dBm (100mW) max
- **Sensitivity:** -148 dBm
- **Range:** 10+ km line-of-sight, 2-5 km typical

2.1.4 Power System

- **Primary Battery:** 2x 18650 Li-ion (3000mAh each)
- **Total Capacity:** 6000mAh @ 3.7V = 22.2Wh
- **Solar Panel:** 5V 1W Monocrystalline
- **Charge Controller:** TP4056 with protection
- **Low Voltage Cutoff:** 3.0V per cell

2.1.5 Environmental Protection

- **Enclosure Rating:** IP67 (waterproof/dustproof)
- **Operating Temperature:** -20°C to $+60^{\circ}\text{C}$
- **Storage Temperature:** -40°C to $+85^{\circ}\text{C}$
- **Humidity:** 0-95% RH non-condensing
- **Shock/Vibration:** MIL-STD-810G compliant

2.2 Software Specifications

2.2.1 Operating System

- **Framework:** Arduino ESP32 Core
- **RTOS:** FreeRTOS v10.x
- **Development:** PlatformIO/Arduino IDE
- **Language:** C++ with Arduino libraries

2.2.2 Data Structures

```
// Cow Health Data Packet
struct CowHealthData {
    char deviceID[16];           // "COW-A1B2C3D4E5F6"
    uint32_t timestamp;          // Unix timestamp
    float temperature;           // Body temperature (°C)
    float latitude;               // GPS coordinates
```

```

float longitude;           // GPS coordinates
uint8_t gpsQuality;       // GPS fix quality (0-9)
float activityLevel;      // Activity magnitude
uint8_t movementState;   // 0=Rest, 1=Walk, 2=Active
uint8_t ruminationState;  // 0=None, 1=Ruminating
uint8_t batteryLevel;     // Battery percentage (0-100)
uint8_t alertFlags;       // Bit flags for alerts
uint16_t checksum;       // Data integrity check
};

```

2.2.3 Power Management

```

// Sleep Schedule
#define ACTIVE_DURATION_MS    5000    // 5 seconds active
#define SLEEP_DURATION_MS    25000   // 25 seconds sleep
#define DEEP_SLEEP_THRESHOLD  3.3     // Voltage for deep sleep
#define CRITICAL_BATTERY     10       // Critical battery %

// Wake-up Sources
- Timer wake (every 30 seconds)
- Temperature threshold exceeded
- High activity detection
- Low battery alert

```

2.3 Performance Specifications

2.3.1 Power Consumption

State	Current (mA)	Duration	Daily Usage
Active	120	5s/30s cycle	4.8 Ah
Deep Sleep	0.01	25s/30s cycle	0.02 Ah
GPS Acquisition	150	30s (cold start)	0.3 Ah
LoRa Transmission	140	0.5s per packet	0.1 Ah
Total Daily			5.22 Ah

2.3.2 Battery Life Calculation

Solar Generation (6h effective sun):

$$1W \div 3.7V = 270mA \times 6h = 1.62 \text{ Ah/day}$$

Net Consumption: $5.22 - 1.62 = 3.6 \text{ Ah/day}$

Battery Life: $6000mAh \div 3600mAh = 1.67 \text{ days minimum}$

With 50% solar efficiency: 4-7 days typical

2.3.3 Accuracy Specifications

- **Temperature Accuracy:** $\pm 0.5^\circ\text{C}$ (calibrated)
- **GPS Accuracy:** ± 3 meters CEP (50% confidence)

- **Activity Detection:** $\pm 5\%$ error rate
- **Battery Monitoring:** $\pm 2\%$ accuracy
- **Timestamp Accuracy:** ± 1 second (NTP synced)

3. MILK STATION SPECIFICATIONS

3.1 Hardware Specifications

3.1.1 Main Controller

- **Microcontroller:** ESP32-WROOM-32
- **Processing Power:** Same as Cow Node
- **Memory:** 4MB Flash, 520KB RAM
- **Interfaces:** 2×UART, 2×I2C, 4×SPI, 18×GPIO

3.1.2 Milk Monitoring Sensors

Sensor	Model	Measurement	Range	Accuracy	Interface
Flow Meter	YF-S201	Volume flow	1-30 L/min	$\pm 2\%$	Pulse counting
Load Cell	5kg Capacity	Weight	0-5 kg	$\pm 0.1\%$	HX711 ADC
pH Sensor	SEN0161	Acidity	0-14 pH	± 0.1 pH	Analog
Conductivity	DFR0300	EC/TDS	0-20 mS/cm	$\pm 2\%$	Analog
Temperature	DS18B20	Milk temp	0-50°C	$\pm 0.5^\circ\text{C}$	1-Wire

3.1.3 Identification System

- **RFID Reader:** RC522 (13.56 MHz)
- **Read Range:** 0-60mm
- **Tag Type:** ISO14443A/MIFARE
- **Data Storage:** 1KB per tag
- **Read Time:** <100ms

3.1.4 User Interface

- **Display:** 20×4 Character LCD with I2C
- **Backlight:** Blue LED with dimming
- **Input:** 4×4 Matrix keypad
- **Status LEDs:** Red/Yellow/Green indicators
- **Audio:** Active buzzer for alerts

3.1.5 Control Systems

- **Solenoid Valves:** 2× 12V normally closed
- **Flow Control:** Automated start/stop

- **Sample Valve:** Quality testing port
- **Emergency Stop:** Manual override button

3.2 Milk Quality Standards

3.2.1 Quality Parameters

Parameter	Acceptable Range	Warning Level	Reject Level
pH	6.6 - 6.8	6.4-6.6, 6.8-7.0	<6.4, >7.0
Temperature	35-39°C	32-35°C, 39-42°C	<32°C, >42°C
Conductivity	4.0-5.5 mS/cm	5.5-6.5 mS/cm	>6.5 mS/cm
Flow Rate	2-8 L/min	1-2, 8-10 L/min	<1, >10 L/min

3.2.2 Mastitis Detection Algorithm

```
bool detectMastitis(float conductivity, float temperature) {
    // High conductivity indicates somatic cell count
    if (conductivity > 6.5) return true;

    // Combined indicators
    if (conductivity > 5.8 && temperature > 40.0) return true;

    // Trend analysis (3-day average)
    if (conductivityTrend > 1.5) return true;

    return false;
}
```

3.3 Data Management

3.3.1 Session Data Structure

```
struct MilkSession {
    char stationID[16];    // "MILK-A1B2C3D4E5F6"
    char cowID[8];        // "COW001"
    uint32_t startTime;    // Session start timestamp
    uint32_t endTime;     // Session end timestamp
    float totalVolume;    // Total milk volume (L)
    float totalWeight;    // Total milk weight (kg)
    float avgpH;          // Average pH
    float avgTemp;        // Average temperature (°C)
    float avgConductivity; // Average conductivity (mS/cm)
    uint8_t qualityGrade; // A=1, B=2, C=3, Reject=4
    bool mastitisFlag;    // Mastitis detected
    uint16_t dataPoints;  // Number of sensor readings
};
```

3.3.2 Real-time Monitoring

- **Sampling Rate:** 1 Hz (1 sample/second)
 - **Data Buffer:** 300 samples (5 minutes)
 - **Transmission:** Every 30 seconds to Gateway
 - **Local Storage:** 1000 sessions on SD card
-

4. GATEWAY SPECIFICATIONS

4.1 Hardware Specifications

4.1.1 Main Controller

- **Microcontroller:** ESP32-WROOM-32
- **Enhanced RAM:** 8MB PSRAM (optional)
- **Storage:** 16MB Flash + SD card slot
- **Real-time Clock:** DS3231 with battery backup

4.1.2 User Interface

- **Display:** 3.5" TFT LCD (480×320 pixels)
- **Touch Screen:** Resistive touch interface
- **Colors:** 65K colors (16-bit)
- **Brightness:** Auto-adjusting with ambient sensor
- **Screen Saver:** 5-minute timeout

4.1.3 Communication Interfaces

Interface	Specification	Purpose
LoRa	SX1276 915MHz	Receive from nodes
WiFi	802.11 b/g/n	Internet connectivity
Ethernet	W5500 module	Wired network backup
4G/LTE	SIM800L module	Cellular backup
USB	Type-C connector	Programming/debug

4.1.4 Storage and Backup

- **Local Database:** SQLite on SD card
- **Capacity:** 32GB SD card (2+ years data)
- **Backup Power:** 12V 7Ah SLA battery
- **Runtime:** 8+ hours on battery
- **Auto-shutdown:** At 20% battery remaining

4.2 Software Architecture

4.2.1 User Interface Framework

```

// Screen Management
enum ScreenType {
    SCREEN_DASHBOARD = 0,
    SCREEN_COW_LIST,
    SCREEN_COW_DETAIL,
    SCREEN_MILK_PRODUCTION,
    SCREEN_ALERTS,
    SCREEN_SETTINGS,
    SCREEN_REPORTS
};

// Touch Event Handling
struct TouchEvent {
    uint16_t x, y;
    bool pressed;
    uint32_t timestamp;
};

```

4.2.2 Data Aggregation

- **Collection Rate:** Real-time from LoRa
- **Processing:** Moving averages, trend analysis
- **Storage:** Time-series database structure
- **Compression:** Delta compression for historical data
- **Sync Interval:** Every 5 minutes to cloud

4.2.3 Alert System

```

enum AlertLevel {
    ALERT_INFO = 0,           // Informational
    ALERT_WARNING = 1,        // Requires attention
    ALERT_CRITICAL = 2        // Immediate action needed
};

struct Alert {
    uint8_t level;
    char deviceID[16];
    char message[128];
    uint32_t timestamp;
    bool acknowledged;
};

```

4.3 Performance Specifications

4.3.1 Processing Capacity

- **Concurrent Nodes:** 50+ cow nodes, 5+ milk stations
- **Data Rate:** 1000+ packets/hour
- **Response Time:** <100ms for touch events

- **Screen Refresh:** 30 FPS for animations
- **Memory Usage:** <70% RAM utilization

4.3.2 Network Performance

Protocol	Throughput	Latency	Reliability
LoRa RX	1.2 kbps	100-500ms	>99%
WiFi	10+ Mbps	<50ms	>95%
Ethernet	10 Mbps	<10ms	>99%
4G/LTE	1+ Mbps	100-300ms	>90%

5. COMMUNICATION PROTOCOL

5.1 LoRa Physical Layer

5.1.1 RF Parameters

- **Frequency:** 915 MHz ± 0.5 MHz
- **Bandwidth:** 125 kHz
- **Spreading Factor:** 7-12 (adaptive)
- **Coding Rate:** 4/5, 4/6, 4/7, 4/8
- **TX Power:** 2-20 dBm (1.6-100mW)
- **Receiver Sensitivity:** -148 dBm

5.1.2 Data Rate vs Range

Spreading Factor	Data Rate	Range (km)	Airtime (50 bytes)
SF7	5.47 kbps	2-3 km	56.6 ms
SF8	3.13 kbps	3-5 km	103.2 ms
SF9	1.76 kbps	4-6 km	185.3 ms
SF10	0.98 kbps	6-8 km	371.2 ms
SF11	0.54 kbps	8-10 km	741.4 ms
SF12	0.29 kbps	10+ km	1483.8 ms

5.2 Protocol Stack

5.2.1 Packet Structure

```

+++++
+ Preamble + Header + Device ID + Payload + CRC + End +
+ (8 bytes)+(4 bytes)+ (8 bytes) +(1-255 B)+(2 B)+(1 B)+
+++++

```

Header Format:

- Protocol Version (4 bits)
- Message Type (4 bits)

- Payload Length (8 bits)
- Sequence Number (8 bits)
- Timestamp (8 bits - seconds since hour)

5.2.2 Message Types

Type	ID	Description	Max Size
COW_DATA	0x01	Health monitoring data	64 bytes
MILK_DATA	0x02	Milk production data	128 bytes
ALERT	0x03	Emergency alerts	32 bytes
CONFIG	0x04	Configuration commands	64 bytes
ACK	0x05	Acknowledgment	8 bytes
HEARTBEAT	0x06	Keep-alive signal	16 bytes

5.3 Error Handling

5.3.1 Automatic Repeat Request (ARQ)

- **Retry Attempts:** 3 maximum
- **Timeout:** 2× expected airtime
- **Backoff:** Exponential (1s, 2s, 4s)
- **Duplicate Detection:** Sequence number tracking

5.3.2 Forward Error Correction

- **Reed-Solomon:** RS(255,223) encoding
- **Interleaving:** Byte-level interleaving
- **Error Recovery:** Up to 16 byte errors

6. POWER ANALYSIS

6.1 System Power Budget

6.1.1 Cow Node Power Profile

Component	Active (mA)	Sleep (mA)	Duty Cycle	Avg (mA)
ESP32	80	0.01	16.7%	13.3
GPS	25	0	8.3%	2.1
Sensors	10	0	16.7%	1.7
LoRa TX	120	0	0.5%	0.6
LoRa RX	12	0	1.0%	0.1
Total Average				17.8 mA

6.1.2 Solar Charging Analysis

Daily Energy Consumption:

$$17.8\text{mA} \times 24\text{h} = 427.2 \text{ mAh/day} = 1.58 \text{ Wh/day}$$

Solar Panel Output (5V 1W, 6h effective):

$$1\text{W} \times 6\text{h} = 6 \text{ Wh/day theoretical}$$

$$6 \text{ Wh} \times 0.8 \text{ efficiency} \times 0.7 \text{ weather} = 3.36 \text{ Wh/day practical}$$

Net Energy: $3.36 - 1.58 = 1.78 \text{ Wh/day surplus}$

Battery Life: Indefinite with adequate sun exposure

6.2 Thermal Management

6.2.1 Operating Temperature Ranges

Component	Min (°C)	Max (°C)	Typical (°C)
ESP32	-40	+85	+25 to +45
Battery	-20	+60	+10 to +40
LCD	-20	+70	+5 to +50
Sensors	-40	+85	Variable

6.2.2 Thermal Protection

- **Over-temperature Shutdown:** $>65^{\circ}\text{C}$
 - **Under-temperature Protection:** $<-15^{\circ}\text{C}$
 - **Battery Heater:** Activated below 0°C
 - **Ventilation:** Passive cooling vents
-

7. SAFETY AND COMPLIANCE

7.1 Electrical Safety

7.1.1 Safety Standards Compliance

- **IEC 60950-1:** Information Technology Equipment Safety
- **FCC Part 15:** Radio Frequency Devices
- **CE Marking:** European Conformity
- **RoHS:** Restriction of Hazardous Substances

7.1.2 Protection Features

- **Overvoltage Protection:** MOVs and TVS diodes
- **Overcurrent Protection:** Resettable fuses
- **ESD Protection:** ESD suppressors on all I/O
- **Isolation:** Optoisolated sensitive circuits

7.2 Food Safety Compliance

7.2.1 Materials

- **Food Contact Surfaces:** FDA-approved stainless steel 316L
- **Gaskets and Seals:** FDA-approved silicone
- **Cleaning:** CIP (Clean-in-Place) compatible
- **Sanitization:** Compatible with standard dairy sanitizers

7.2.2 Cleaning Procedures

Daily Cleaning:

1. Disconnect sensors from milk line
2. Flush with warm water (40-45°C)
3. Circulate alkaline cleaner (2% solution)
4. Rinse with potable water
5. Sanitize with iodophor or chlorine solution
6. Final rinse and air dry

7.3 Data Security

7.3.1 Encryption

- **Data at Rest:** AES-256 encryption
- **Data in Transit:** TLS 1.3 for cloud communication
- **LoRa Security:** AES-128 with rolling keys
- **Key Management:** Hardware security module

7.3.2 Privacy Protection

- **Data Anonymization:** Optional cow ID hashing
- **Local Storage:** No cloud dependency required
- **User Consent:** Configurable data sharing
- **GDPR Compliance:** Right to erasure implemented

8. TESTING AND VALIDATION

8.1 Environmental Testing

8.1.1 Test Standards

- **IP67 Waterproof:** IEC 60529 standard
- **Vibration:** ASTM D4169 (livestock movement)
- **Temperature Cycling:** -20°C to +60°C
- **Humidity:** 95% RH non-condensing
- **UV Exposure:** ASTM G154 (solar radiation)

8.1.2 Durability Testing

Test	Duration	Criteria
Drop Test	50 drops from 1.5m	No functional failure
Submersion	30 min at 1m depth	No water ingress

Test	Duration	Criteria
Vibration	8 hours at 5G	All functions operational
Temperature	1000 cycles	<1% drift in accuracy

8.2 Performance Validation

8.2.1 Field Testing Protocol

Phase 1: Laboratory Testing (2 weeks)

- Sensor accuracy validation
- Communication range testing
- Battery life verification
- Software functionality

Phase 2: Controlled Farm Testing (4 weeks)

- 5 cows with reference monitoring
- Milk quality comparison with lab results
- System reliability assessment
- User interface evaluation

Phase 3: Production Testing (8 weeks)

- 25 cows full deployment
- Veterinarian validation of health alerts
- Milk production correlation analysis
- Long-term reliability data

8.2.2 Acceptance Criteria

- **Uptime:** >99% system availability
- **Accuracy:** <5% error vs reference methods
- **Range:** >2km communication in typical farm
- **Battery:** >7 days without solar charging
- **User Satisfaction:** >4.5/5 rating

9. MANUFACTURING SPECIFICATIONS

9.1 Production Requirements

9.1.1 Assembly Process

PCB Assembly:

1. SMD component placement (pick-and-place)
2. Reflow soldering (lead-free SAC305)
3. Through-hole component insertion
4. Wave soldering for THT components
5. Cleaning (no-clean flux residue)
6. Automated optical inspection (AOI)

7. In-circuit testing (ICT)
8. Functional testing

Final Assembly:

1. PCB installation in enclosure
2. Antenna attachment and testing
3. Battery pack assembly
4. Solar panel integration
5. Waterproof seal application
6. Final quality inspection
7. Programming and calibration
8. Packaging and documentation

9.1.2 Quality Control

- **Incoming Inspection:** 100% critical components
- **Process Control:** Statistical process control
- **Final Testing:** 100% functional test
- **Traceability:** Full component genealogy
- **Yield Target:** >98% first-pass yield

9.2.2 Inventory Management

- **Safety Stock:** 4 weeks production
- **Reorder Points:** Based on lead times
- **Just-in-Time:** For high-volume components
- **Consignment:** For expensive ICs

10. MAINTENANCE AND SUPPORT

10.1 Preventive Maintenance

10.1.1 Maintenance Schedule

Interval	Task	Time Required
Daily	Visual inspection, alert review	10 minutes
Weekly	Sensor cleaning, battery check	30 minutes
Monthly	Calibration verification	1 hour
Quarterly	Firmware updates, full test	2 hours
Annually	Battery replacement, deep clean	4 hours

10.1.2 Maintenance Tools Required

- **Basic Tools:** Screwdriver set, multimeter
- **Calibration:** pH buffers, conductivity standards
- **Cleaning:** Appropriate dairy sanitizers
- **Software:** Maintenance app on tablet/phone

10.2 Technical Support

10.2.1 Support Tiers

Tier 1: Basic Support (Local technician)

- Installation assistance
- Basic troubleshooting
- Routine maintenance
- User training

Tier 2: Advanced Support (Regional expert)

- Complex troubleshooting
- Firmware updates
- Sensor calibration
- Performance optimization

Tier 3: Engineering Support (Development team)

- Hardware/software issues
- Custom modifications
- Advanced analytics
- Product improvements

10.2.2 Remote Diagnostics

- **Cloud Monitoring:** 24/7 system health monitoring
- **Predictive Maintenance:** ML-based failure prediction
- **Remote Updates:** Over-the-air firmware updates
- **Performance Analytics:** Trend analysis and optimization

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