# FIRMWARE DETAILS – REAL-TIME SMART AGRICULTURE SYSTEM ON µT-KERNEL 3.0

**Entry ID: 34686**
**Category: RTOS Application – Student**

---

## 2. Firmware Overview

The firmware implements a real-time irrigation controller on the Renesas EK-RA8D1 evaluation kit using µT-Kernel 3.0. It integrates:

- Capacitive soil moisture sensing (ADC).
- Pump control via relay driver.
- RTOS task scheduling for deterministic operation.
- Serial logging for debugging and judge evaluation.

This firmware demonstrates low-latency, deterministic actuation — the pump is triggered within milliseconds when soil moisture drops below threshold.

---

## 2. Firmware Architecture

The firmware is structured into 8 modular µT-Kernel tasks, ensuring scalability and clarity:

| Task | Priority | Function |
|---|---|---|
| SensorTask | High | Poll soil moisture via ADC, preprocess readings (moving average filter). |
| ControlTask | Medium | Compare moisture level with threshold; actuate pump via GPIO relay. |
| CommTask | Medium | Handle UART communication for debug logs and external dashboard sync. |
| SafetyTask | High | Watchdog reset, pump cut-off on abnormal current/overvoltage. |
| LogTask | Low | Store moisture readings & pump states in local memory for review. |
| TimerTask | High | µT-Kernel timer for periodic sampling (every 500 ms). |
| ISR Handlers | Highest | Immediate response to ADC conversion complete and relay control events. |
| IdleTask | Lowest | Enter low-power mode when no tasks pending. |

---

**3. Firmware Modules**

- **ADC Driver Module**
  Configures RA8D1 ADC to read soil sensor (0–3.3V). Includes digital filter for noise rejection.
- **GPIO + Relay Driver Module**
  GPIO pin drives relay IN → external 12V pump. Includes fail-safe cutoff.
- **RTOS Task Manager**
  µT-Kernel objects: semaphores, message queues for sensor→control data exchange.
- **Threshold Logic Module**
  Defines soil moisture threshold (configurable). Hysteresis logic prevents pump chattering.
- **Serial Debug Module**
  Sends periodic sensor values and pump status at 115200 baud for judges.

---

**4. Hardware Integration**

- **Board: Renesas EK-RA8D1.**
- **Moisture Sensor (Capacitive) → ESP32 GPIO pin (3.3V logic).**
- **Relay Module (5V) → GPIO pin with external transistor driver.**
- **Pump (12V DC) → Relay output + external PSU.**
- **Grounding: All grounds (board + pump PSU + sensor) common.**

---

**5. RTOS Task Flow**

1. Moisture Read: SensorTask triggers ADC conversion.
2. Data Processing: Filtered reading sent to ControlTask via message queue.
3. Threshold Decision: If Moisture < X% → pump ON; else pump OFF.
4. Relay Actuation: GPIO toggled; ISR confirms successful switching.
5. Logging: Values logged for analysis.
6. Idle Mode: MCU enters low-power state until next timer tick.

---

**6. Key Firmware Parameters**

- ADC Sampling Interval: 500 ms (configurable).
- Moisture Threshold: 30% soil moisture (adjustable).
- Relay Pulse Width: Maintained until moisture crosses threshold + hysteresis margin.
- Serial Baud Rate: 115200 bps, 8N1.
- Memory Usage: ~40 KB Flash, ~8 KB RAM.
- Latency: <200 ms from sensor change to pump trigger.

---

**7. Unique Features**

- True RTOS determinism: Preemptive task scheduling ensures sensor→pump latency <200 ms.
- Fail-safe design: SafetyTask stops pump on abnormal conditions.
- Configurable thresholds: Easily tunable for different soil types.
- Power efficiency: IdleTask leverages RA8D1 low-power modes.
- Scalability: Can add humidity/temperature tasks or wireless comm without changing core logic.

---

**8. Testing & Verification**

- Test Case 1: Dry soil → ADC < threshold → Pump ON within 3s.
- Test Case 2: Wet soil → ADC > threshold → Pump OFF within 3s.
- Test Case 3: Sensor disconnected → SafetyTask halts pump.
- Acceptance Criteria: ≥95% reliability over 20 cycles; logs match hardware action.

---

**9. Future Firmware Enhancements**

- Integration of wireless comm (ESP32 Wi-Fi) for cloud logging.
- Expansion to multi-sensor fusion (temperature, humidity, rainfall).
- Addition of AI-based predictive irrigation scheduling.