Plant Pal — Smart Soil Watering System

Overview

Plant Pal is an embedded microcontroller system that monitors soil moisture, air temperature, and humidity to determine when a plant needs watering.
It operates through well-defined system states, uses interrupts, performs manual ADC sampling, keeps real-time event logs, and provides user feedback through LEDs, an LCD, and a small motor or pump.

Functional Requirements

Inputs & Sensors

Component	Purpose	Implementation Notes
Soil moisture sensor	Measures soil wetness via ADC	Use direct register-level ADC (no analogRead())
DHT11(temperature Sesor)	Reads temperature & humidity	Library allowed
Start/Stop button	Enables or disables the system	Handled via ISR interrupt
Reset button	Clears error state	Polled input

Outputs

Component	Function
LCD Display	Shows soil status, temperature, and humidity
LED Indicators	Show states — Yellow for Disabled, green for Idle, blue for Running and red for Error
Pump or Fan	Waters the plant when soil is dry
RTC Module	Logs timestamps for state changes and events
Serial Port	Sends event messages (e.g., "Soil dry at 3:22 PM") to a host computer

System States

State	Description	Behavior
DISABLED	System off	Turn Yellow led on, no sensor activity; ISR monitors Start button.
IDLE	Monitoring normal conditions	Turn Green led on; reads sensors every minute; transitions to RUNNING if soil dry.
RUNNING	Watering active	Turn Blue led on; pump runs until soil returns to normal; logs activation time.
ERROR	Fault state	Turn Red led on, pump off, LCD shows "Sensor Error" or "Low Water", reset button returns to IDLE if resolved.

Timing and Event Handling

- Use the RTC for accurate timestamps and event logging.
- Use millis() for 1-minute intervals (no delay() calls).
- Start/Stop button handled via external interrupt (attachInterrupt() allowed).
- LCD updates once per minute during active states.
- All transitions are reported over Serial with timestamps.

Allowed Libraries

Feature	Library Use
RTC module	Allowed
LCD display	Allowed
DHT11 sensor	Allowed
Motor/relay control	Allowed
GPIO, ADC, Serial functions	Use register-level code only

Hardware List

- Arduino Mega 2560

- Soil moisture sensor (analog input)

- DHT11 temperature/humidity sensor

- RTC module (I²C)

- 16×2 LCD (I²C or parallel)

- 4 LEDs for state indication

- Push buttons (Start/Stop and Reset)

- Pump or small DC motor for watering control

System overview (what always runs)

- Clock & logging: The RTC is your time source; every state change and noteworthy event is timestamped and reported over Serial.

- Scheduler: One central "tick" based on millis() drives periodic actions (no delay()):

    - Sensor cadence: once per minute in active states.
    - LCD cadence: refresh once per minute (and immediately on state changes).

- Buttons:

    - Start/Stop: external interrupt; toggles between DISABLED ↔ IDLE, and can stop RUNNING/ERROR back to DISABLED.
    - Reset: polled; only affects ERROR (tries to recover to IDLE if the fault is gone).

- LEDs: Always indicate the current state: red, green, blue and yellow.

Power-up & initialization

1. Boot & self-check (instant):

    - Initialize peripherals (ADC in manual mode, GPIO directions, LCD, DHT11, RTC, motor/relay control, Serial).
    - If any hard fault is detected (e.g., ADC not ready, RTC missing), enter ERROR; otherwise proceed.

2. Enter DISABLED by default:

    - Turn Yellow on!

    - Actuators: pump OFF.

    - Sensors: no periodic sampling (conserve power/avoid noise).

    - ISR for Start/Stop is armed.

    - LCD: "System Disabled" + time.

    - Log: "System entered DISABLED @ ".

Start/Stop interrupt behavior (any time)

- If in DISABLED and Start is pressed (ISR):

    - Timestamp and log "Start pressed".

    - Transition → IDLE (see below).

- If in IDLE or RUNNING or ERROR and Stop is pressed (ISR):

    - Timestamp and log "Stop pressed".
    - Force actuators safe (pump OFF), clear minute timers, transition → DISABLED.

IDLE (monitoring)

Goal: Watch the environment and be ready to water if soil is dry; lightweight behavior.

- Entry actions:

    - LEDs: Green led on.

    - Pump Off.

    - LCD immediate update: "IDLE" + last known readings or "waiting for next sample".

    - Log: "Entered IDLE @ " IDLE Time

- Minute tick (every 60s via millis()):

1. Soil moisture sample (manual ADC):

    - Take multiple quick reads (e.g., 3–5) and average to reduce noise.

    - Validate reading range to catch open/short conditions.

2. DHT11 read:

    - Get temperature & humidity, validate checksum/status from the library.

3. LCD update:

    - Line 1: Soil status (e.g., "Soil: Dry/OK + raw%").

    - Line 2: "T: {number} °C H: yy%".

4. Decision logic:

- Sensor fault? (ADC out of plausible range, DHT error):

    - Transition → ERROR ("Sensor Error"); log fault type and values.

- Soil dry? (below dry threshold with hysteresis and debounce):

    - Require "dry" for N consecutive samples (e.g., 2–3 minutes) to avoid false starts.

    - When confirmed, transition → RUNNING; log "Soil dry—watering started".

- Soil OK: remain in IDLE.

- While waiting: no blocking—system remains responsive to the Start/Stop ISR.

RUNNING (watering)

Goal: Water until soil returns to acceptable moisture to protect plant and hardware.

- Entry actions:

    - LEDs: Blue led on.

    - Pump ON (or open relay).

    - Record watering session start time: log event with timestamp.

    - LCD immediate update: "RUNNING: Watering…".

- Safety rails active while RUNNING:

    - Max continuous run time (e.g., 2–5 minutes default): if exceeded → ERROR ("Timeout / Low Water?").

    - Thermal/overcurrent hooks (optional if hardware supports): if tripped → ERROR.

    - Minute tick loop: same cadence as IDLE.

- Minute tick (every ~60s):

1. Soil re-sample (manual ADC): average & validate.

2. DHT11 read (for logging/LCD).

3. LCD update: show "Watering t=mm:ss", current soil %, T/H.

4. Decision logic:

- Sensor fault? → ERROR ("Sensor Error"), pump OFF, log.

- Soil recovered? (≥ wet threshold using hysteresis):

    - Confirm with 1–2 consecutive OK samples to prevent chattering.

    - Then stop pump, log "Watering stopped; soil OK".

    - Transition → IDLE.

- Still dry: continue; keep monitoring max-time limit.

- Exit actions (on any transition): pump OFF, log stop reason & duration.

ERROR (fault handling)

Goal: Fail safe, inform the user, and recover only when the problem is gone.

- Entry actions:

    - Turn LED Red on

    - Pump OFF (force safe).

    - Freeze any watering timers.

    - Log specific fault ("Sensor Error", "Low Water", "Pump Timeout", etc.) with raw readings.

    - LCD: big, clear message (e.g., line 1: "ERROR"; line 2: reason).

- While in ERROR:

    - No watering; Start/Stop still works to go to DISABLED.

    - The system continues minute-tick diagnostics to see if conditions normalize (so the Reset button can succeed). This includes:

        - Re-reading soil and DHT11.

        - Optional: checking a reservoir/float switch if present (for "Low Water" case).

    - Reset button (polled):

        - When pressed:

            - If the original fault condition is no longer present, log "Reset acknowledged—fault cleared", then transition → IDLE.

- If the fault persists, stay in ERROR; update LCD ("Still in Error") and log the failed reset attempt with current readings.

LCD update policy (clarity without flicker)

- Immediate updates on every state change.

- Periodic updates once per minute in IDLE/RUNNING/ERROR.

- Keep messages compact and consistent so a user can read state + last sample at a glance.

Debounce, hysteresis, and stability (avoid false actions)

- Start/Stop button: hardware/ISR debounce (time-based ignore window or edge validation).

- Soil dryness:

  - Hysteresis: Two thresholds (e.g., Dry < 35%, Wet > 45%).
  - Debounce: require N consecutive dry/ok confirmations before switching states.

- Sensor sanity checks:

  - ADC plausible range; reject saturated readings as faults.

  - DHT11 checksum/status must pass; otherwise fault.

Logging & timestamps (what you report)

- State changes: DISABLED↔IDLE, IDLE→RUNNING, RUNNING→IDLE, any → ERROR, ERROR→IDLE (after reset).

- Watering sessions: start time, stop time, duration, average soil level during session.

- Faults & recoveries: type, raw values, time.

- Periodic notes (optional): brief heartbeat once every few minutes ("IDLE heartbeat T/H & soil%") to help debugging.

Edge cases & priorities

- Start/Stop during RUNNING: immediately safe-stop pump, go to DISABLED, log user abort.

- Power loss mid-run: on reboot, you start in DISABLED; previous session can't be resumed—log "Unexpected restart".

- Repeated faults: if the same error occurs X times in Y minutes, escalate the LCD message ("Check wiring/sensor") but remain in ERROR until Reset + recovery.

- Empty reservoir (if applicable): treat like a dedicated Low Water fault (go to ERROR); only recover after refill + Reset.