Garden Auto Project

Hero / Landing of project page

Hero image

Team Project

May 2025 - June 2025

Automated Multi-Zone Garden Irrigation System

Iterative prototype — current focus on Version 3 reliability and fluid isolation

(put tags here) Mechanical, Electrical, Controls, Software

Instruction:
Use "**garden-v2-final-pic**" as a faded, full-width hero background image. Treat it as a backdrop (not a foreground image).
Increase all hero text to a standard desktop web scale in the final build; small text here is only due to PDF layout constraints.
Ensure sufficient contrast (overlay gradient or blur) so hero text remains readable over the background image.

Project Overview

- Automated indoor irrigation system for multi-zone plant watering
- Uses a single motorized distribution hub instead of multiple solenoid valves
- Soil-moisture feedback enables adaptive, zone-specific watering

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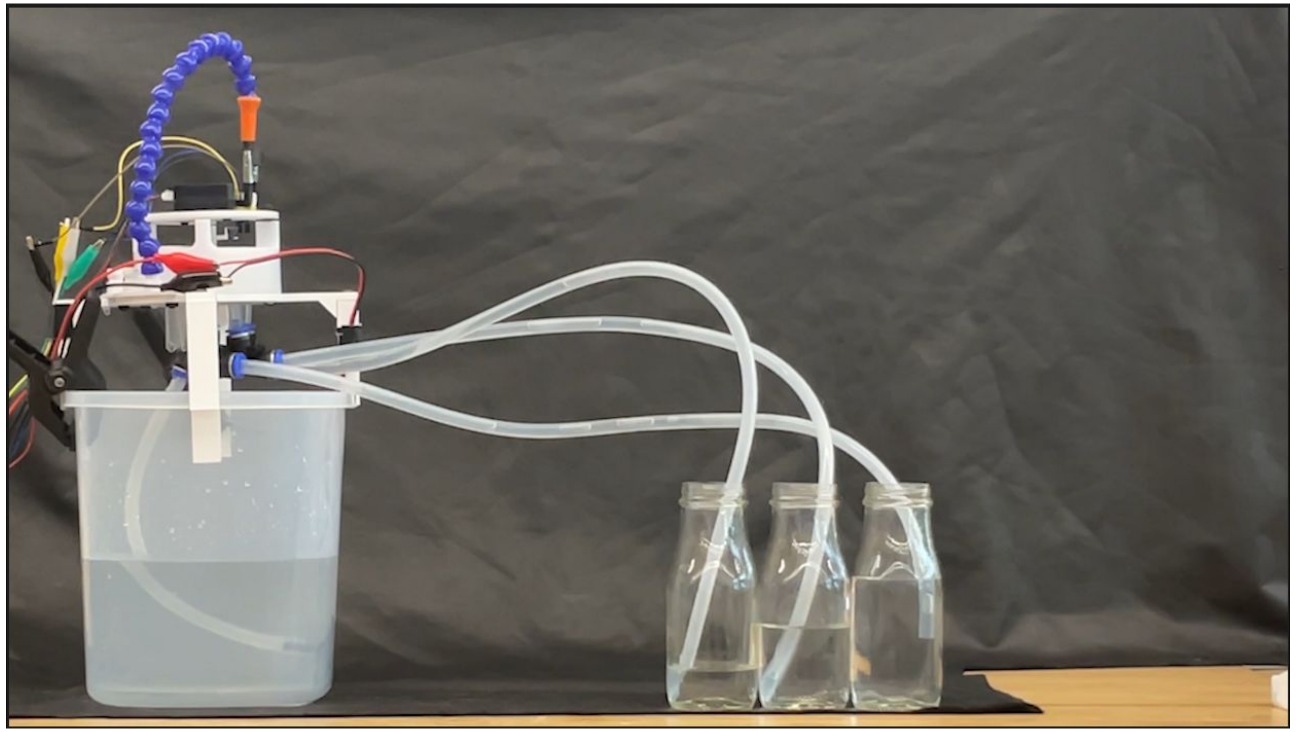
System Overview & Design Intent

Design Objective
Conventional multi-zone irrigation systems rely on individual solenoid valves per zone, increasing cost, wiring complexity, and system footprint. These systems are poorly suited for compact indoor growing environments where scalability and adaptability are critical.

Core Idea / Solution
Rather than using per-zone solenoid valves, this system employs a single-actuator mechanical distribution hub that sequentially routes water to multiple zones. This approach reduces hardware count while maintaining precise, zone-specific control through scheduling and sensor feedback.

Outcome
The final prototype successfully demonstrated automated, sensor-driven irrigation across multiple zones using minimal actuation hardware. The system reduced complexity and cost while remaining modular and manufacturable using 3D printing and off-the-shelf components.



Name of png file is “garden-v2-section1”
(Image represents full system; avoid zooms, arrows, or callouts in this section)

Section 2

High Level System Model (section header)

Black-Box System Model (subheader, smaller than header)

Inputs

- Water supply (pressure & flow)
- Electrical power
- Soil moisture sensor signals
- Time / schedule (RTC or software timing)
- User-defined settings (thresholds, schedules)
- Environmental disturbances (plant uptake, evaporation)

→

Processes

- Measure soil moisture
- Evaluate watering demand
- Select irrigation zone & Regulate water distribution
- Calibrate and Control actuator position
- Enforce timing and safety constraints

→

Outputs

- Regulated water delivery to zones
- System state feedback
- Log and report system state

This black-box model represents the garden irrigation system at a functional level. External inputs such as water supply, electrical power, time, and soil moisture measurements are processed by control logic that determines watering demand and routes flow through a compact distribution hub.

The system outputs regulated water delivery to individual zones while maintaining target soil moisture levels and providing system state feedback.

System Functions, Parameters and Constraints

Functions

Track time and scheduling state

Sense soil conditions

Evaluate watering demand

Select irrigation zone

Regulate water flow

Distribute water to selected zones

Report system state

Parameters

Soil moisture thresholds per zone

Watering duration per cycle

Flow rate per outlet

Number of zones

Scheduling intervals (time & frequency)

Actuator speed & positioning resolution

Constraints

Pump pressure & flow capacity

Electrical power availability

Indoor space constraints

Budget limitations

Water isolation from printed parts

Leak prevention & safety requirements

(Render three equal-width columns. Each column contains a titled card with bullet points only. No icons, no images.)

Section 4

System Architecture (structural, not functional)

Overall System Architecture

Hydraulic subsystem

- Reservoir / supply
- Pump + check valve / filter (if used)
- **Distribution hub** (single-motor multi-zone routing)
- Zone tubing / emitters

Sensing subsystem

- Soil moisture sensors (per zone)
- Water level sensor / float switch (optional but nice)
- Flow sensor / pressure switch (optional)

Control + firmware subsystem

- Scheduler (RTC / timekeeping)
- Decision logic (thresholds + rules)
- State machine (idle / water / fault)
- Calibration routines (per-sensor mapping)

Electronics + power subsystem

- Microcontroller
- Motor driver (hub)
- Pump driver (MOSFET/relay)
- Power regulation (battery/adapter → 5V/3.3V rails)
- Protection (fuse, reverse polarity, etc.)

Mechanical + packaging subsystem

- Hub enclosure + seals
- Hose fittings / manifolds
- Mounting / serviceability

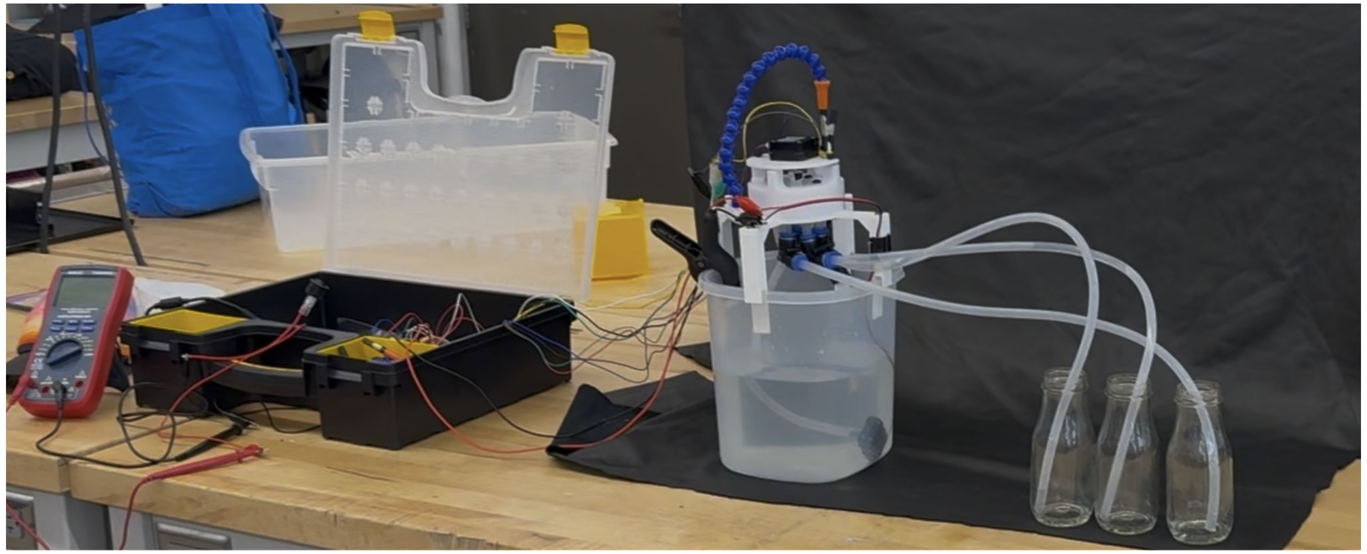
Subsystems

Water path (physical): reservoir → pump → distribution hub → zone hoses → plants
Signal path (control): sensors + clock → controller → actuators (pump + hub motor) → water
Power path: battery/PSU → controller + drivers + actuators

Render all sections using editable layout components only (HTML/JSX/Markdown/CSS).
Do not generate raster images (PNG/JPG) or bake text into graphics.
Diagrams must be constructed using semantic layout blocks or SVG only if explicitly requested.

Section 5

Final System implementation



File name “garden-v2-final-pic”
This is the file to be used for the image on the left

This project demonstrates mechanical system synthesis, iterative prototyping, and cross-domain integration of hardware, electronics, and embedded control.

Status: Functional prototype meeting initial design requirements.
Current focus: Compact mechanical distribution and single-actuator control.
Next iteration: Fluid-isolated components to improve reliability.

Final Video, File name “Portfolio-Final-section-vid”

Achieved Outcomes

- Reduced actuation hardware from **N solenoids to a single motor** via mechanical routing
- Enabled per-zone watering schedules with live soil-moisture feedback
- Designed for fabrication using 3D printing and off-the-shelf hardware only

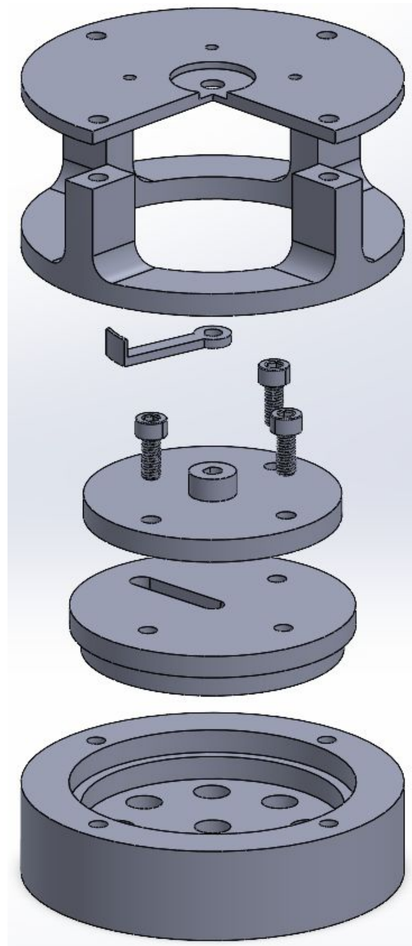
This prototype validates the core system concept and informs the ongoing V3 redesign.

Distribution Hub Sub-System

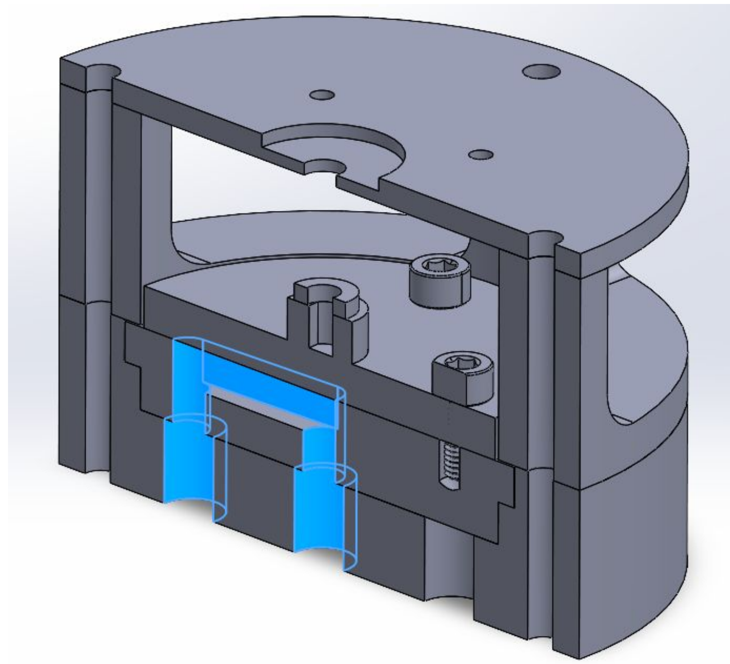
- Purpose
  - The distribution hub routes water from a single supply to multiple plant zones using a single actuator, enabling compact packaging, reduced cost, and simplified control compared to multi-valve systems. It serves as the mechanical interface between the pump and downstream irrigation lines while enforcing controlled, sequential water delivery.

- Design Requirements
  - Route water to multiple outlets using **one motor**
  - Minimize footprint for indoor use
  - Prevent cross-flow between zones
  - Be manufacturable without CNC machining
  - Be compatible with low-cost hobby pumps
  - Isolate water from printed components

- Final implementation (Current)
  - One motor replaces multiple solenoids
  - Compact cylindrical form factor
  - Modular outlet count
  - Designed for printed parts + off-the-shelf hardware



(this will be a gif as an mp4 file that i want to play on repeat, the file name is “garden-v2-explode-animation”)



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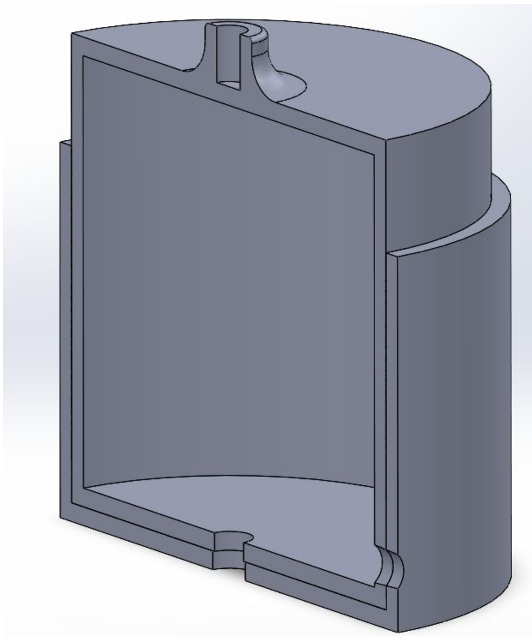
Distribution Hub Sub-System - Iterations



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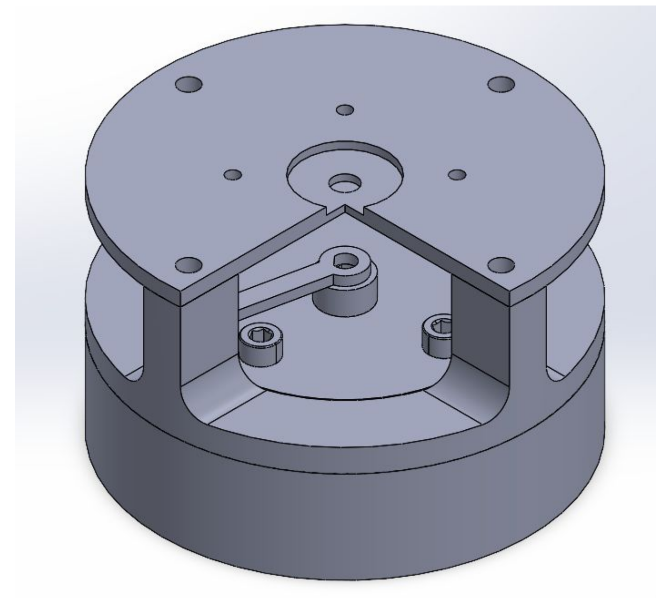

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Iteration 1 — Concept Validation

This initial iteration explored a simple mechanical routing concept using concentric inner and outer cylinders to sequentially align a single inlet with multiple outlets. The design minimized interface count and sealing complexity, allowing rapid fabrication and bench-level validation of the core switching mechanism.

While mechanically functional, this version operated in isolation and was not integrated into a complete irrigation system. As a result, routing logic, control integration, and long-duration sealing performance were not yet addressed.

Iteration 2 — System Integration

The second iteration integrated the mechanical hub into a full irrigation system, including pump operation, control logic, and multi-zone routing. This exposed real-world constraints related to sealing, printed-part tolerances, and repeatability under sustained pressure and cycling.

Although the mechanical routing concept remained effective, increased system integration revealed leakage paths and manufacturability limitations that were not apparent during isolated bench testing, motivating a reassessment of how fluid interfaces were handled within the hub.

Iteration 3_toggle — Dry Switching Architecture (Planned)

The next iteration shifts away from rotating wetted interfaces entirely by decoupling mechanical switching from fluid sealing. The proposed architecture uses a dry mechanical switching mechanism to sequentially connect a main supply hose to individual zone hoses, eliminating direct water contact with moving printed components.

This approach is intended to reduce leakage risk, improve long-term reliability, and relax tolerance requirements by isolating fluid sealing to static interfaces.

By minimizing prolonged water contact with printed polymers in food-growing applications, the design also supports improved material hygiene and food safety considerations while retaining the single-actuator, sequential routing strategy.

Key takeaway: Increased system integration exposed sealing and manufacturability limitations, motivating a shift toward dry mechanical switching.

Electrical & Sensing Subsystem — Design & Validation

Purpose

This subsystem provides sensing, actuation, and timing inputs required to operate the irrigation system autonomously. It interfaces low-voltage sensors and control logic with higher-power actuators while maintaining electrical isolation, repeatability, and safe operation during development and testing.

Final Implementation

- **Controller:** Arduino Mega used to support multiple sensors, timers, and actuator channels
- **Actuators:**
  - Stepper motor driver for hub positioning
  - DC pump switched via logic-level MOSFET with flyback protection
- **Sensors:**
  - Optical sensor for hub calibration / homing
  - Soil moisture sensors per zone (capacitive)
- **Timing:**
  - RTC behavior simulated using a button-based input system during early development to validate scheduling logic before hardware integration

Calibration & Absolute Positioning

The distribution hub is driven by a stepper motor, which provides high repeatability for relative positioning but operates as an open-loop system and cannot inherently determine absolute angular position after power loss or reset.

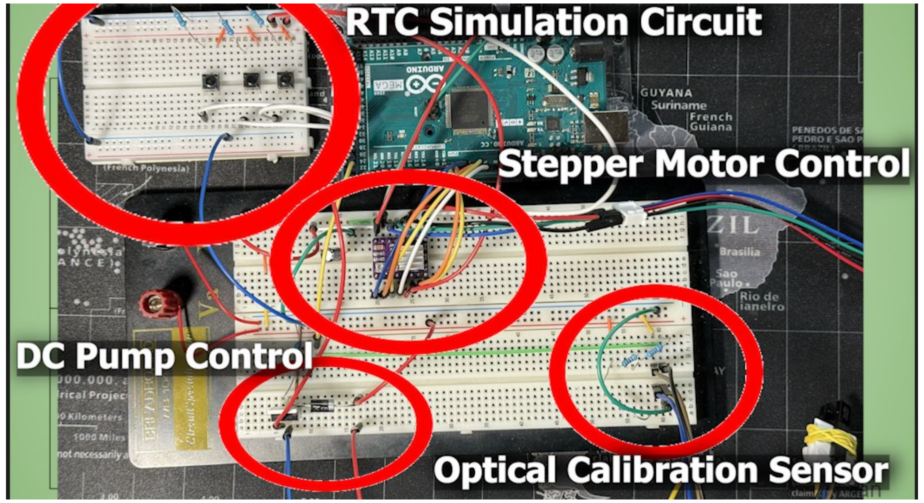
To address this limitation, an optical interrupter sensor is used to establish a repeatable mechanical home reference at startup. A dedicated calibration arm integrated into the rotating hub passes through the optical sensor once per revolution, defining a known zero position.

At system initialization, the hub rotates until the arm triggers the sensor, allowing the controller to re-zero the angular position before normal operation. This prevents cumulative positioning error, ensures consistent zone alignment, and enables reliable long-term operation without requiring closed-loop motor control.

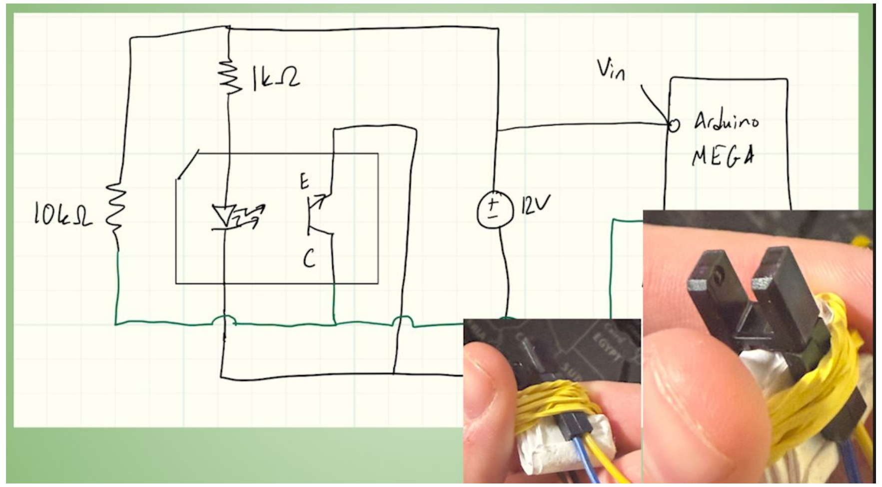
Trade-offs & Design Decisions

- Arduino Mega selected over smaller MCUs to simplify early integration and support multiple I/O channels during rapid prototyping
- Breadboard-based validation prioritized flexibility and observability over electrical robustness during early development
- Button-based RTC simulation used to accelerate firmware validation before committing to dedicated timing hardware

Instruction: Scale text up to standard body and heading sizes during implementation. Reduced font size in this PDF is due only to slide layout constraints, not intended final readability.



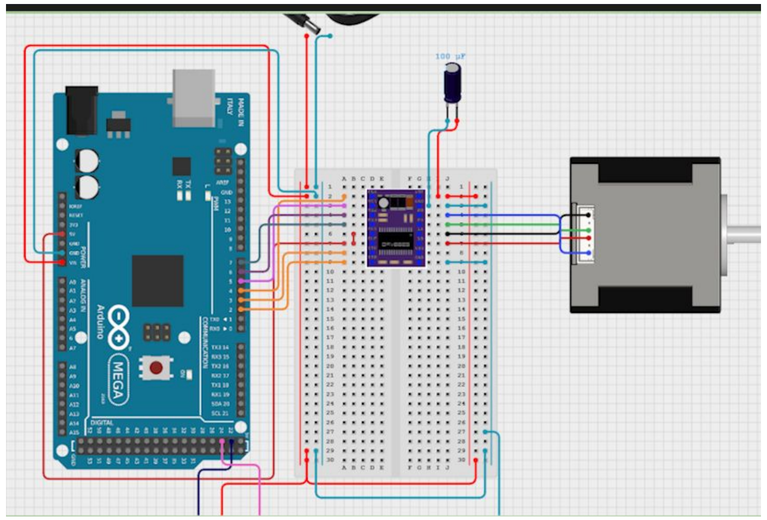
Caption - Early integration testbed used to validate firmware, scheduling logic, and actuator control prior to final hardware packaging.
File name “garden-whole-breadboard”



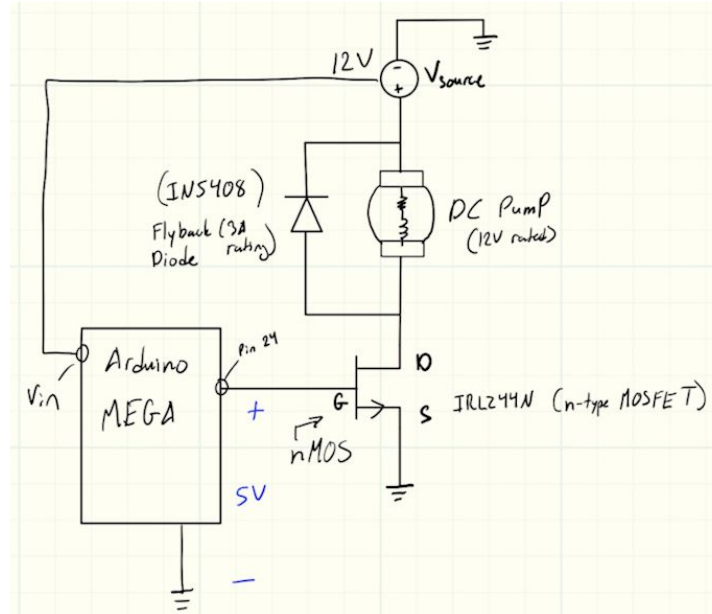
Caption - Optical interrupter circuit used for hub homing and absolute position calibration at startup.
File name “garden-optical-circuit”

Continuation of section 8

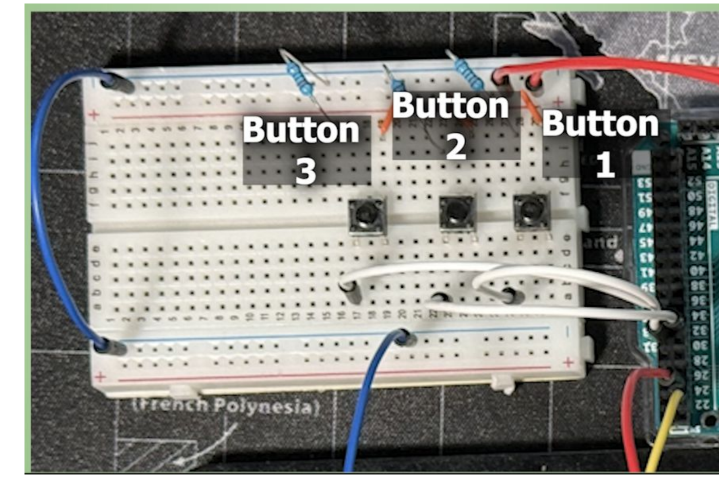
Electrical & Sensing Subsystem (Supporting Circuits)



Caption - Stepper motor control circuit used to position the mechanical distribution hub.
File name “garden-stepper-circuit”



Caption - DC pump switching circuit with flyback protection for inductive load isolation.
File name “garden-pump-control-circuit”



Caption - RTC Simulation Interface (Development Tool)
File name “garden-RTC-sim-circuit”