Prototype Overview

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January 26, 2026

1 Prototype System Overview

This prototype exemplifies a single module of an embedded greenhouse lighting system, modelled using the finite state machine (FSM) in Figure 1.

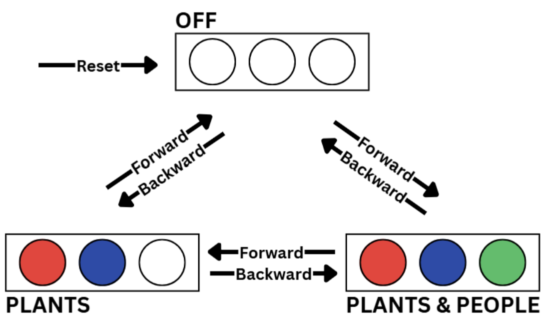

Figure 1: State diagram illustrating the control logic of the LED system controlled by two buttons.

The FSM defines three operating states: **OFF** (all LEDs off), **PLANTS** (red and blue LEDs on), and **PLANTS & PEOPLE** (all LEDs on). System behavior is controlled through two push-button inputs, **Forward** and **Backward**, which cyclically advance or reverse the system state. The **Reset** input indicates the system's initial state.

1.1. Software Subsystem

The software subsystem implements the finite state machine described above using CircuitPython on the Raspberry Pi Pico. Iterations informing the final control architecture are documented in Folder 04.1.2_Software and Folder 04.2.2_Software.

1.2. Electrical Subsystem

The electrical subsystem provides the interface between the software control logic and the physical system. It is shown in Figure 2.

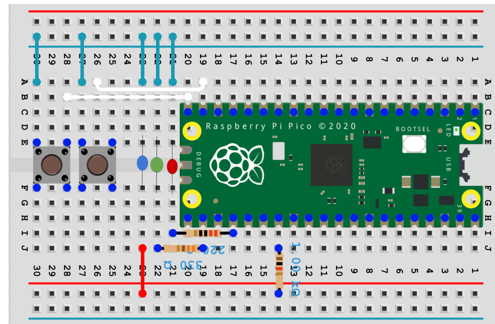

Figure 2: Breadboard layout of the electrical subsystem showing the various components.

The final circuit layout was refined through multiple iterations, documented in Folder 04.1.1_Electrical and Folder 04.2.1_Electrical.

1.3. Structural Subsystem

The structural subsystem protects the electrical components while improving the aesthetics of the prototype. It is shown in Figure 3.

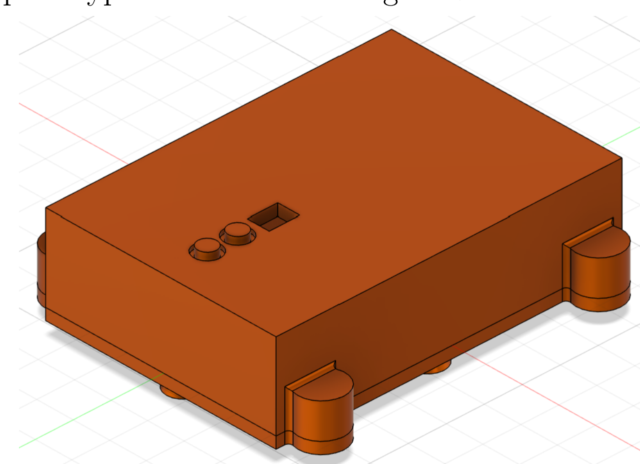

Figure 3: CAD screenshot illustrating the structural subsystem of the prototype.

The enclosure was designed using CAD tools and fabricated using PLA via 3D printing at MyFab. The final design provides access to the pushbuttons and USB port, and is fastened using screws for reliable assembly and disassembly. The structural design evolved through multiple iterations, documented in Folder 04.1.3_Structural and Folder 04.2.3_Structural.

2 Integrated Prototype

The final prototype integrates the software, electrical, and structural subsystems into a single functional unit, as shown in Figure 4.

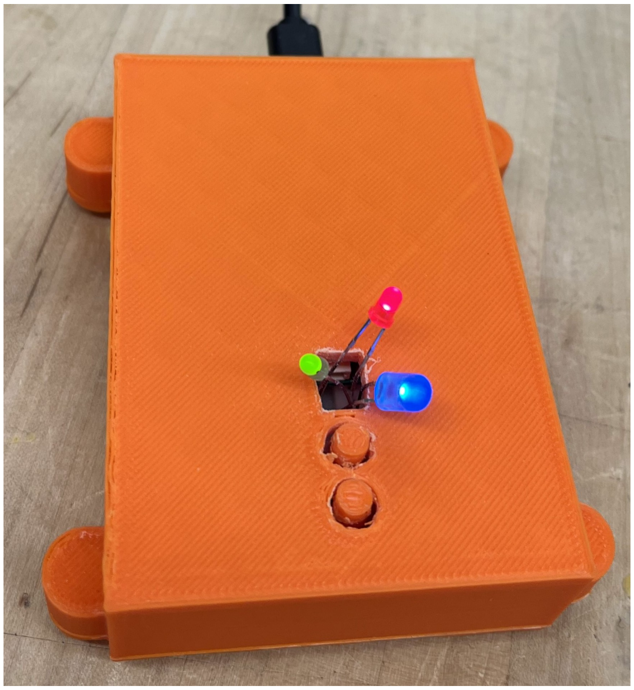

Figure 4: Final integrated prototype of the control system housed in a 3D-printed enclosure.

2.1. Major Challenges Faced

Several challenges emerged during system integration that were not apparent during isolated subsystem development. The initial enclosure iteration prevented the breadboard from fully seating due to mispositioned alignment divots and an overextended internal wall, highlighting the need to account for enclosure tolerances and internal clearances earlier in the design process. These lessons were directly applied in a subsequent CAD iteration, which incorporated increased clearances, removal of divots, and other refinements that resolved the structural issues.

Integration also revealed a brightness imbalance between the blue and green LEDs during combined operation, leading to an adjustment of the blue LED resistor value to improve visual consistency. Artifacts documenting these challenges and the iterative integration process are provided in Folder 04.3_Integration.

3 Prototype Performance

A verification framework was created to assess the prototype's performance against the specification. This framework and detailed testing artifacts are found in Folder 04.4_Verification. The prototype met all the specifications; an example of verification is outlined below.

A key structural requirement verified was that internal components remain fixed relative to the enclosure during handling and operation. The assembled prototype was subjected to manual translation and rotation in multiple orientations, after which the position of a reference component was measured relative to the enclosure walls. Positional differences before and after testing were recorded in a verification spreadsheet and compared against a ± 0.5 mm tolerance, chosen based on the minimum perceptible distance of the human eye. All measured displacements were within tolerance, confirming that the enclosure adequately constrained the electrical subsystem during normal operation.

4 Key Design Decisions

- **Screwed enclosure:** Screws were chosen over snap-fit mechanisms to ensure reliable retention despite print tolerances, while allowing repeated assembly and disassembly for servicing.
- **LED placement:** LEDs were placed symmetrically and centered to improve visual balance and clearly convey system states.
- **Forward/Backward button architecture:** A bidirectional control scheme was selected so every state is reachable from any other state, improving usability and ensuring full state accessibility.
- **Button caps:** Button caps were used instead of exposed pushbuttons to address poor ergonomics observed in the first prototype, where limited finger clearance could not be improved due to circuit constraints.
- **Resistor values:** Resistor values of 220 Ω, 1000 Ω, and 330 Ω were selected for the red, blue, and green LEDs respectively to prevent LED damage and achieve balanced perceived brightness, with final adjustments informed during integration.