# Equipment

## a) Mirroring Grow-tents in both WSU and CPP

The system is built around a Raspberry Pi 4 single-board computer acting as the central automation hub, running the open-source control software Mycodo. It continuously monitors water conditions (including pH, electrical conductivity, temperature, level, and flow) and air conditions (such as temperature, humidity, vapor pressure deficit, $CO_2$) and controls actuators (relays, peristaltic pumps, lights, fans, humidifier) to keep the growing environment within user-specified setpoints. Specifically, the system uses four peristaltic pumps to dose acid, base, nutrient A and nutrient B solutions, enabling automatic adjustment of pH and nutrient strength (EC) of the reservoir. The system is modular and scalable, designed originally for an NFT (nutrient film technique) layout but applicable to larger systems, and integrates live monitoring via camera and a dashboard for real-time data and alerts.

**Additional information on grow-tent instrumentation**

Table 1: Instrumentation and measured variables

| Variable | Instrument / Sensor | Range | Accuracy | Sampling interval |
|---|---|---|---|---|
| Electrical Conductivity (EC) | Atlas EZO-EC K = 1.0 | 0–20 mS cm$^{-1}$ | ± 2 % | 1 min |
| pH | Atlas EZO-pH | 0–14 pH | ± 0.02 pH | 1 min |
| Volumetric water content | Teros 12 capacitance probe | 0–100 % | ± 2 % | 1 min |
| Water temperature sensor | Atlas scientific PT-1000 probe | −55 °C to +125 °C | ±0.1 °C | 1 min |
| Substrate temperature | DS18B20 RTD | 0–70 °C | ± 0.1 °C | 1 min |
| Irrigation flow / pressure | Omega FPR300 + WIKA A-10 | 0–5 L min$^{-1}$ 0–10 bar | ± 1 % | 10 s |
| Microclimate (Temperature, relative humidity, carbon dioxide) | BME280 + SenseAir S8 | −10–50 °C 0–100 % RH 0–2000 ppm $CO_2$ | ± 0.5 °C, ± 3 % RH, ± 30 ppm | 1 min |
| Energy use (pump) | Shelly EM modbus meters | 0–3 kW | ± 0.5 % | 1 min |
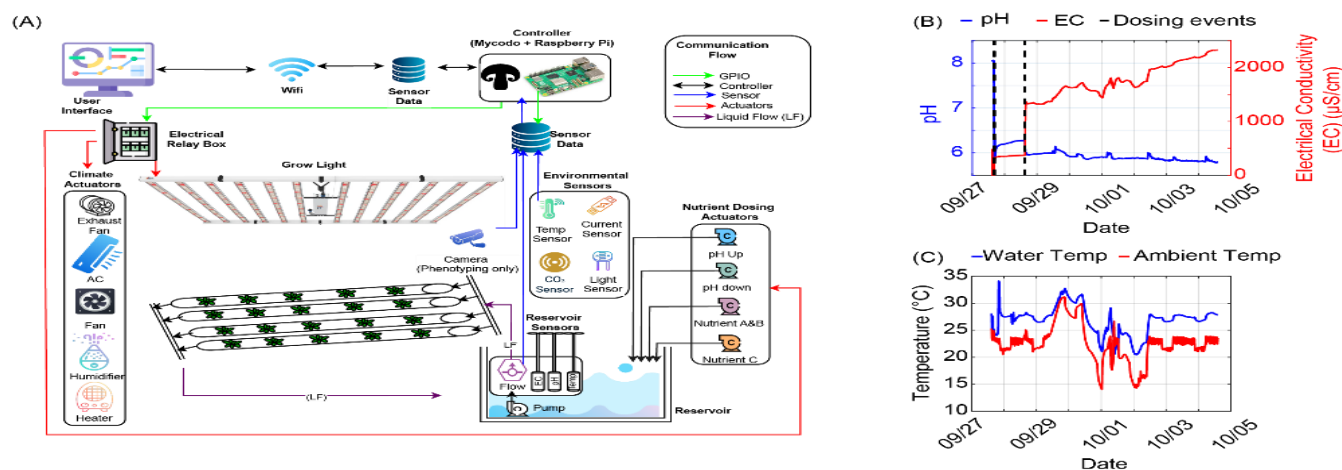


**Figure 1:** IoT-enabled sensing and actuation network controlled by a Raspberry Pi running Mycodo. Sensors monitor pH, electrical conductivity (EC), temperature, humidity, and nutrient dosing events while data are transmitted to a cloud gateway for analysis. (B) Example time-series

of pH (blue) and EC (red) with vertical lines marking nutrient-injection events. (C) Water- and ambient-temperature trends recorded during the same period.
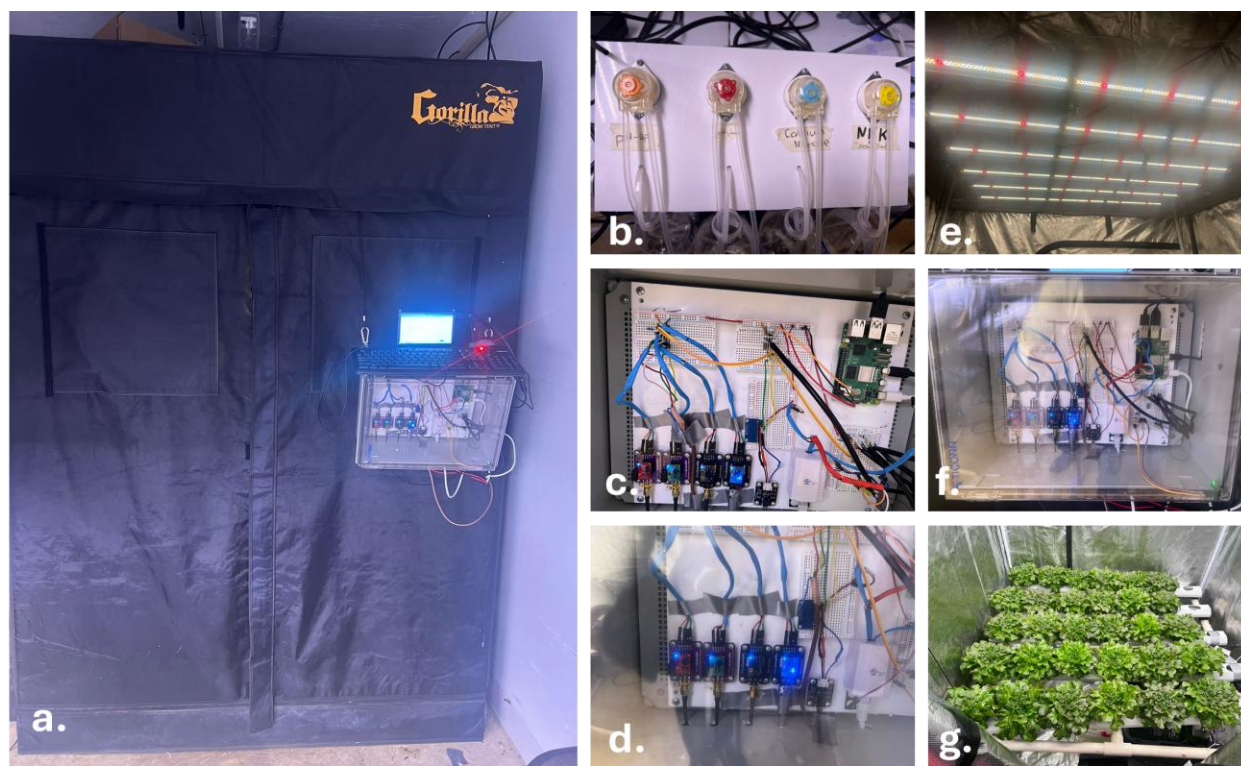


**Figure 2:** The mirroring grow-tents and their components

### b) California State Polytechnic University, Pomona (CPP)

**1. AGRIscapes Greenhouse Systems**

The AGRIscapes greenhouse is equipped with an integrated suite of instrumentation supporting the proposed CCRO–Digital Twin–Agentic AI platform for controlled-environment horticulture (CEH). The system will include a pilot-scale Closed-Circuit Reverse Osmosis (CCRO) skid engineered for brackish and recycled water desalination. The system already consists of a conventional RO unit (HydroLogic Evolution-RO1000 with ChloraShield carbon pre-filters and sediment filters) which will enable the reference system study for comparison. The CCRO desalination skid interfaces directly with fertigation and sensor networks, providing boundary-condition data for digital-twin modeling and artificial intelligence (AI) control development.

The fertigation control assembly is managed through Bluelab IntelliDose, Pro Controller, and pH Controller systems integrated with Autogrow EC and pH probes and Hanna HI1285-7 multiparameter probes. These units monitor solution pH, electrical conductivity (EC), temperature, and dosing events at high temporal resolution. The controllers are networked through Raspberry Pi gateways running Mycodo 8.12 automation software for time-series acquisition and synchronization with the digital-twin database.

Environmental and climate variables are regulated through Ideal-Air ultrasonic humidifiers, Can-Fan Max-Fan 12″ (1708 CFM) exhaust units, Can-Filter 150 activated-carbon filters, and Quest 105/155/205 dual dehumidifiers with Quest F9 air movers for air exchange. Temperature and

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humidity are automatically logged through a TrolMaster Hydro-X lighting and climate-control network with RJ12 sensor adaptors (LMA-14) and Hydro-X communication cable sets (ECS-2). These systems allow programmable climate control and uniform microenvironment maintenance across replicated greenhouse bays.

Lighting is provided by AgXano LED grow modules with DC Flex dimming and M12 wiring systems, delivering full-spectrum PAR control for simulation of diurnal and seasonal light regimes. The lighting system interfaces with the Hydro-X controllers for energy-demand logging and synchronization with AI scheduling algorithms. These systems are currently being procured.

## 2. Instrumentation for Data Collection and Process Monitoring

Real-time sensor data include flow (Omega FPR-series turbine meters), line pressure (WIKA A-10 transmitters), root-zone temperature (PT-1000 probes), and microclimate (BME280, APDS-9306, and SenseAir S8 for temperature, RH, light, and $CO_2$). A Bluelab Pulse Meter and Autogrow nutrient sensors provide rapid EC, moisture, and temperature profiling of substrates. Data are transmitted via LAN-based Mycodo gateways, forming the backbone of the predictive digital-twin architecture.

The project also employs a LI-COR LI-600 porometer and fluorometer for crop-level gas exchange and photosynthetic efficiency measurements. This instrument quantifies stomatal conductance, leaf temperature, and fluorescence parameters under varying fertigation regimes, enabling mechanistic links between plant physiology and AI-driven irrigation control.

## 3. Environmental Safety

Routine system maintenance and sanitation are supported by a NFS-1 fogging disinfection unit and ULV electric fogger for sterile nutrient-line cleaning and algae control.

## 4. Computational Infrastructure

Computational resources for AI model development, simulation are supported by the College's Computer and Data Science Laboratory, equipped with multi-core workstations (Intel Xeon processors, 128 GB RAM, NVIDIA RTX GPUs) running Python 3.11, TensorFlow 2.14, PyTorch 2.0, and Docker environments for reproducible research. The local server hosts the greenhouse data repositories (PostgreSQL/InfluxDB 2.7) and performs model training, Bayesian optimization, and hyperparameter tuning for reinforcement learning and predictive control. The environment is mirrored to secure institutional NAS storage and Microsoft OneDrive for redundancy and collaboration.

### c) Wayne State University (WSU)

## 1. WSU Computing & Information Technology:

The Computing & Information Technology group provides secure and reliable computing environments for faculty, staff, and students at Wayne State University. A Tier 3+ data center is available for any department to host equipment or take advantage of virtual hosting, backups, and storage. A high performance computing grid is also available that can handle projects that require high speed computing, parallel and distributed computing, data management, and computationally intensive applications. The Grid has combined processing power of 6,520 cores with over 17.5TB of RAM and 1.2PB of disk space and is open to any research at WSU.

## 2. Computing labs:

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The student will have access to computers for running codes and working with data. Department of Industrial and Systems Engineering have computing labs that are equipped with 60 PCs for summer camp students to use.

3. **Indoor/outdoor faming equipment**:

The team will has access to thermostat, ventilation, irrigation, grow light, and gardening tools, as well as galvanized bed, toolbox, and irrigation, soil, fillers, and pots. The team also has access to one indoor hydroponic growth tent.

4. **Arduino**: The team has about 50 kits of Arduino.

5. **Immersive Modleing and Digital Twinning Equipment**:

Dr. Masoud's lab is equipped with immersive and wearable technologies such as three HTC Vive Pro eye – Arena Bundle with extra trackers and six Oculus Quest II, three Microsoft HoloLens II, several Leap Motion controllers, and two Alienware gaming laptop with Intel(R) Core(TM) i9 Processor and NVIDIA(R) GeForce RTX(TM) 2070 8GB GDDR6 with software such as Unity Game Engine. In addition, the team will access to WSU's VR lab, allowing the team to have access to an additional 10 VR head mounted displays.