**HARDWARE REQUIREMENTS**

1. **CONTROL SYSTEM**

* Arduino Mega or ESP32 microcontroller
* USB cable for programming
* Power supply (12V, 5A minimum)
* Breadboard and jumper wires

1. **MOVEMENT SYSTEM**

* 2x NEMA 17 Stepper Motors
* 2x A4988 or DRV8825 stepper motor drivers
* 2x Linear rails (aluminum V-slot rails)
* 4x V-slot wheels
* GT2 timing belts and pulleys
* 4x Limit switches for homing
* Mounting brackets

1. **IMAGING SYSTEM**

* USB/Wi-Fi camera (minimum 5MP resolution)
* Camera mounting bracket
* LED strips for consistent lighting
* Light diffusers

1. **STRUCTURE**

* Wooden panels for 3x3 box construction
* Screws and mounting hardware
* Corner brackets
* Plant holders/pots (x9)
* Cable management solutions

1. **AUTOMATED WATERING SYSTEM COMPONENTS**

* Submersible water pump (12V or 24V, suitable for hydroponics)
* Water reservoir (capacity: ~5-10 liters)
* PVC tubing for water distribution
* Drip irrigation emitters (x9, one per plant)
* Solenoid valve (for controlled water flow)
* Moisture sensors (x9, one for each plant holder)
* Relay module to control the pump and solenoid valve
* Power adapter for the pump (if not using the main power supply)
* Quick-connect fittings for tubing
* Flow control valves for precise water delivery

1. **NETWORK MODULE FOR REMOTE MONITORING**

* ESP32 or ESP8266 Wi-Fi module (if not integrated into the control system)
* IoT platform (e.g., Blynk, ThingSpeak, or Node-RED) for real-time monitoring and control
* Temperature and humidity sensors (e.g., DHT22 or AM2301)
* Light intensity sensor (e.g., BH1750 or TSL2561)
* Data logging module (e.g., microSD card module)
* Real-Time Clock (RTC) module (e.g., DS3231) for accurate time-keeping
* LCD or OLED display (optional, for local monitoring)
* Buzzer or indicator LEDs for alerts
* Smartphone or tablet for app-based control

1. **TOOLS NEEDED**

* Screwdriver set
* Wire strippers
* Soldering iron and solder
* Measuring tape
* Level
* Power drill
* Wood saw
* Multimeter for troubleshooting
* Hot glue gun for securing components (optional)

**Step-by-Step Plan for Building a 3x3 Vertical Farming System with Disease Detection and Automation**

**Phase 1: Planning and Preparation**

1. **Understand the Functional Requirements**:
   * Movement system to position the camera over plants.
   * Disease detection using a camera.
   * Automated watering system.
   * Remote monitoring via a network module.
2. **Acquire Components**:
   * Gather all the listed hardware components.
   * Ensure compatibility between components (e.g., power ratings, connectors).
3. **Design the System Layout**:
   * Create a blueprint for the 3x3 structure, positioning for rails, plant holders, and camera.
   * Plan wiring paths for power, sensors, and communication.

**Phase 2: Build the Structure**

1. **Assemble the Wooden Frame**:
   * Cut wooden panels to size for a 3x3 box.
   * Use screws and corner brackets to assemble the frame.
2. **Install Plant Holders**:
   * Secure 9 plant holders evenly spaced within the structure.
3. **Install Linear Rails and Mounting Brackets**:
   * Attach linear rails to the frame for the camera movement system.
   * Install mounting brackets for motors and other components.

**Phase 3: Movement System**

1. **Mount Stepper Motors and V-Slot Wheels**:
   * Attach NEMA 17 stepper motors to the frame.
   * Install V-slot wheels on the camera mount for smooth sliding on rails.
2. **Attach GT2 Timing Belts and Pulleys**:
   * Connect the timing belts to the stepper motors and pulleys.
   * Ensure belts are taut for precise movement.
3. **Install Limit Switches**:
   * Place 4 limit switches at the ends of the rails for homing and movement control.
4. **Connect the Movement System to the Microcontroller**:
   * Wire stepper motors to A4988/DRV8825 drivers.
   * Connect drivers to the microcontroller (e.g., Arduino Mega or ESP32).
   * Wire limit switches to appropriate microcontroller pins.

**Phase 4: Imaging System**

1. **Mount the Camera**:
   * Secure the 5MP camera on a movable bracket attached to the linear rails.
2. **Set Up Lighting**:
   * Attach LED strips around the camera mount.
   * Add light diffusers for even lighting.
3. **Connect the Camera**:
   * Connect the camera to the microcontroller or a computer via USB or Wi-Fi.

**Phase 5: Automated Watering System**

1. **Install the Water Pump and Reservoir**:
   * Position the water reservoir and connect PVC tubing to the pump.
2. **Set Up Drip Emitters**:
   * Attach drip emitters to the tubing, one for each plant holder.
3. **Install Moisture Sensors**:
   * Insert a moisture sensor into each plant holder.
4. **Connect Watering System Components**:
   * Wire the pump to a relay module.
   * Wire solenoid valves (if used) for precise water control.
   * Connect moisture sensors and relays to the microcontroller.

**Phase 6: Network Module for Remote Monitoring**

1. **Set Up the Wi-Fi Module**:
   * Configure the ESP32/ESP8266 for Wi-Fi connectivity.
   * Connect temperature, humidity, and light sensors to the microcontroller.
2. **Integrate IoT Platform**:
   * Use an IoT platform (e.g., Blynk, Node-RED) to display sensor data.
   * Set up triggers for alerts (e.g., low moisture, high temperature).

**Phase 7: Software Development**

1. **Develop Firmware for the Microcontroller**:
   * Write a program to control the movement system, imaging, watering, and sensors.
   * Include homing routines for the movement system.
   * Program the camera to take images and send them to a disease detection model.
2. **Integrate Disease Detection**:
   * Use a pre-trained machine learning model (e.g., TensorFlow Lite) to analyze images.
   * Upload and run the model on a computer or cloud service.
3. **Develop Remote Monitoring Interface**:
   * Create a dashboard on the IoT platform for real-time monitoring.
   * Include controls for manual overrides.

**Phase 8: Testing and Calibration**

1. **Test Movement System**:
   * Calibrate stepper motors and ensure smooth camera movement.
2. **Test Imaging and Lighting**:
   * Capture sample images and check lighting consistency.
3. **Test Watering System**:
   * Validate moisture sensor readings and automate watering cycles.
4. **Test Remote Monitoring**:
   * Ensure data from sensors is updated in real-time on the IoT dashboard.

**Phase 9: Optimization and Deployment**

1. **Fine-Tune Components**:
   * Adjust movement speed, camera focus, and watering thresholds.
2. **Deploy System**:
   * Place the system in its intended environment and monitor for performance.

**Logical Connections Summary**

| **Component** | **Physical Connection** | **Logical Function** |
| --- | --- | --- |
| Microcontroller | Stepper drivers, sensors, relays, camera | Central control of all tasks |
| Stepper Motors | Linear rails, pulleys, timing belts | Move the camera to different plants |
| Camera | Mounted on linear rails, connected to microcontroller/computer | Capture plant images for disease detection |
| Moisture Sensors | Inserted in plant holders, wired to microcontroller | Measure soil moisture for watering decisions |
| Pump and Valves | Connected to reservoir and microcontroller via relay | Automated water delivery |
| IoT Module | Wi-Fi connection, linked to sensors and dashboard | Remote monitoring and control |