ECE 401 Senior Project

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Automated Hydroponics System

Abstract

This project proposes the design of a hydroponics system through the development of several custom electrical subsystems. These include a power supply for reliable voltage delivery, an LED driver to control light intensity, motor control circuitry to manage water and nutrient flow, and a dedicated microcontroller to collect sensor data and manage system timing. The system will monitor key environmental factors such as pH levels through monitoring the conductivity of the water, as well as temperature. Information from the sensors will be used to monitor system behavior in real time, while a user interface will display system status and allow manual input when needed. Together, these subsystems will create a responsive, self-monitoring environment optimized for plant growth.

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Design and Feasibility: Hydroponics System

Introduction

This feasibility study outlines the practicality of developing a hydroponics system through the design and implementation of custom electrical subsystems. The goal of this document is to assess the viability of the proposed project by evaluating potential challenges, resource availability, and alignment with the team's technical expertise. Key areas of focus include power delivery, sensor integration, motor and LED control, and system monitoring. By identifying design constraints, establishing a preliminary design approach, and analyzing execution strategies, this document aims to confirm that the project can be successfully completed within the given timeline and budget. This feasibility study also serves as a planning tool to anticipate potential risks and ensure that the proposed design remains achievable, scalable, and well-supported by accessible components and realistic engineering methods.

Constraints

The automated hydroponics system must adhere to several design constraints, including power, component availability, real-time control, modularity, and budget limitations to ensure efficient resource use.

Power Constraints: The system will require a stable and efficient power supply capable of delivering regulated DC outputs for various components. Voltage rails will include 3.3V for low-power digital circuits, 5V for the microcontroller and sensor modules, and 12V for LED grow lights and water pumps. Power efficiency and thermal management will be critical to prevent overheating and ensure long-term operation. A volume of around 5 gallons must circulate through the hydroponics system to provide sufficient water and nutrients to the plants. Depending on the system size and number of plants grown, a pump rated higher than 12 volts may be necessary. This larger pump would require adjustments in the delivery of regulated DC outputs.

Component Availability: The project will rely on readily available electronic components to minimize procurement risks. Custom-designed circuits, such as the LED driver, MOSFET pump driver, pump controller, and power supply, must utilize standard components available from multiple vendors to mitigate supply chain issues.

Real-Time Control: The system must deliver accurate and timely control over lighting and nutrient delivery. A dedicated microcontroller will manage peristaltic pumps to ensure precise dosing, while the microcontroller will handle sensor monitoring and UI management. Communication between these components must be reliable, with minimal latency.

Modularity & Scalability: The system must support future expansion by facilitating the integration of additional sensors. The microcontroller-based pump controller and LED driver will be designed as independent subsystems, allowing modifications or upgrades without affecting the entire system.

Budget Constraints: The project must remain within the allocated budget of $500 between group members while maintaining high reliability. Cost-effective yet high-quality components will be prioritized, and unnecessary complexity in circuit design will be avoided. The peristaltic pump will be purchased rather than built, as it is primarily a mechanical component and not the central focus of the project's scope.

Safety Constraints:

Ensuring the safety of the automated hydroponics system is a critical consideration throughout the design and implementation phases, particularly in preventing electrical hazards, overheating, and system failures. The power supply will incorporate over-voltage, over-current, and short-circuit protection to safeguard components and reduce fire risks, while proper insulation and grounding will minimize the potential for electric shock. Given the heat generated by buck converters, MOSFET drivers, and high-power LEDs, thermal management strategies such as heat sinks, thermal pads, and active cooling will be employed, with temperature monitoring sensors providing an additional safeguard against overheating. Since the system integrates water and electrical components, all sensor and pump connections will be sealed, and waterproofing measures will be implemented to prevent short circuits. Additionally, LED drivers and MOSFET circuits will be enclosed to prevent accidental contact with live circuits, and high-voltage AC-DC conversion will be handled within a dedicated power module to limit direct user interaction with mains voltage. These safety measures will help ensure the system remains stable, efficient, and secure in an environment where water and electronics must coexist.

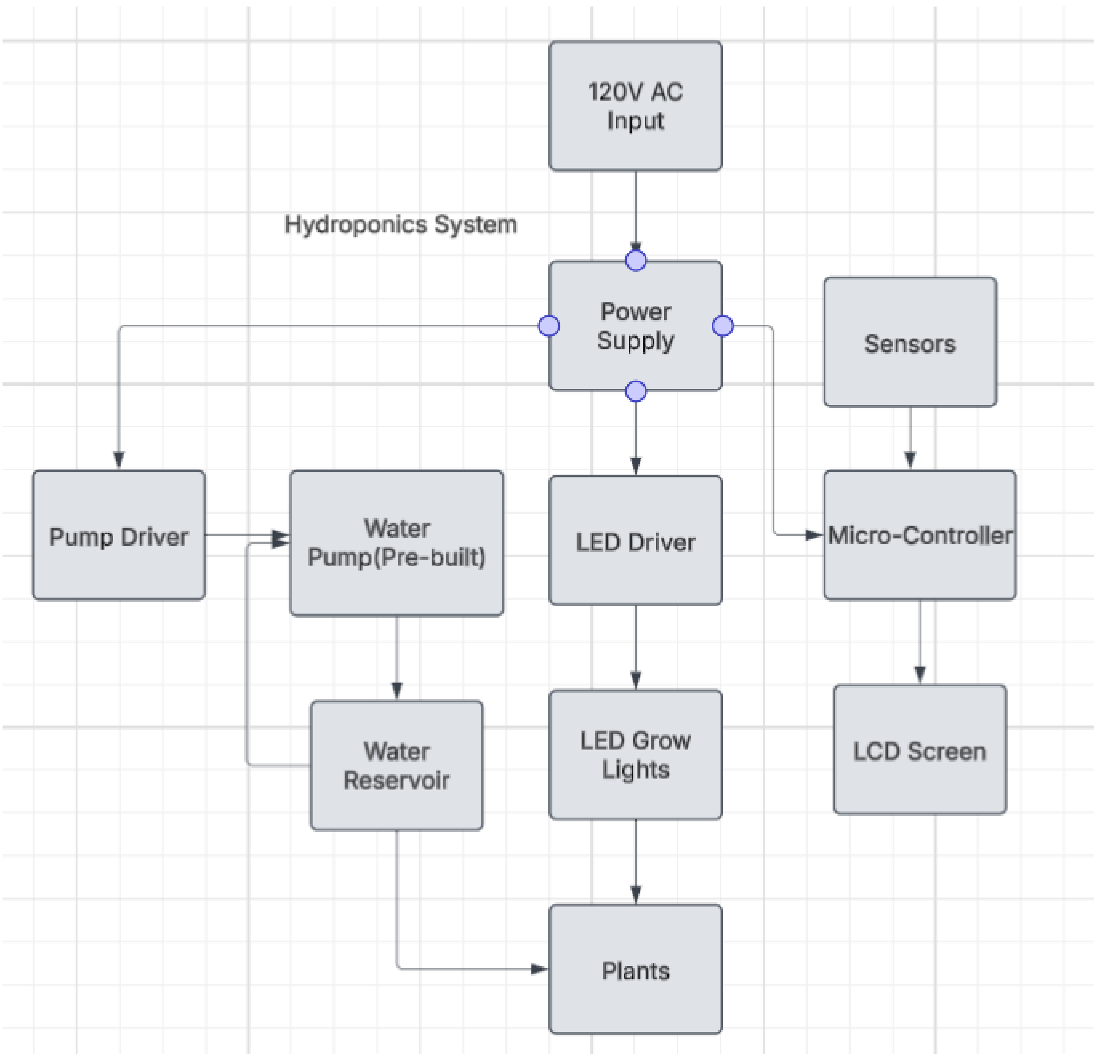
To ensure the safety, reliability, and integrity of the hydroponics system, applicable engineering, environmental, and ethical standards will be followed throughout the design process. Electrical design will align with IEEE standards for low-voltage systems, including practices for proper insulation, overcurrent protection, and grounding in AC-DC power conversion circuits. IPC standards will guide printed circuit board layout, soldering practices, and component placement to support signal integrity and manufacturability.

Environmental considerations will also be incorporated into the design. Lead-free solder and RoHS-compliant components will be used where possible to reduce environmental impact. Energy-efficient design principles—such as minimizing standby power consumption and using efficient buck converters—will be prioritized to reduce the system's energy footprint. Additionally, materials and components will be selected with durability and reusability in mind to support long-term sustainability.

From an ethical standpoint, the project will follow guidelines outlined by the IEEE Code of Ethics. All design work will be conducted honestly and responsibly, with proper attribution of third-party designs, open-source references, and vendor datasheets. User safety, system reliability, and environmental responsibility will be considered in all engineering decisions, and testing will be conducted rigorously to ensure safe and transparent system operation.

Preliminary Design

The automated hydroponics system consists of several interconnected electrical subsystems designed to regulate environmental conditions for plant growth. The primary components include a custom power supply, PWM-controlled LED driver, MOSFET-based pump driver, a potentiometer for the pump, and a micro-controller for sensor monitoring and user interface management.



The hydroponics system is being designed to regulate plant growth through precise control of lighting cycles, water and nutrient delivery, and environmental condition monitoring. The project prioritizes modular subsystem design, minimal software complexity, efficient power management, and a hardware-driven control architecture. These priorities guided early specification choices and directly informed the architecture and electrical requirements of each subsystem.

To meet system power demands, three voltage rails were defined. A 3.3V rail will be used to power the custom microcontroller and low-voltage digital logic. A 5V rail will support sensor modules, the analog-to-digital converter (ADC), and the LCD interface. A 12V rail will supply power to the high-current loads, including the LED grow lights and peristaltic pumps. The estimated current demand is up to 500 mA at 3.3V, 1.5A at 5V, and 6–8A at 12V under full load. Based on these requirements, a custom power supply is being developed to generate all three rails from a 120V AC input. Buck converters with high efficiency (≥90%) will be implemented, and output ripple will be limited to ≤50 mV peak-to-peak on the 3.3V and 5V rails, and ≤100 mV peak-to-peak on the 12V rail. Circuit protection features—including fuses, thermal shutdown, and transient voltage suppression—will be included to ensure safe and stable operation. A power distribution PCB is also being designed to manage rail separation, simplify routing, and provide modular connectivity for each subsystem.

Lighting regulation will be achieved using a PWM-controlled MOSFET driver. The LED array will be powered from the 12V rail and is expected to draw between 3A and 5A, depending on the number and intensity of LEDs in use. PWM signals will be generated by the microcontroller, allowing for adjustable light intensity and fixed photoperiod control. The design intentionally avoids closed-loop light feedback to minimize software complexity and improve system predictability.

Nutrient and water delivery will be handled using 12V peristaltic pumps controlled via on/off logic. The pump is expected to draw between 0.5A and 1A, and will be switched using discrete MOSFET driver circuits triggered by the microcontroller. Delivery timing will be preprogrammed, allowing precise and repeatable control intervals without reliance on sensor feedback. This control scheme simplifies logic while retaining reliable automation.

Environmental sensing is a critical system function. Electrical conductivity, pH, and water temperature will be monitored using analog sensors selected for their relevance to nutrient management and environmental control. Sensor outputs will be routed through low-pass filters and operational amplifiers to reduce noise and improve signal integrity. A dedicated ADC with at least 12-bit resolution will be used to convert analog signals for digital observation. These readings will be displayed in real time through an LCD user interface but will not be used to actively modify system behavior.

The use of a custom-designed microcontroller allows for complete control over I/O allocation, peripheral management, and system timing. All subsystems—power, lighting, pump control, sensing, and display—will be integrated into a single cohesive board layout. This centralized design approach supports precise control, reduces external wiring, and maintains alignment with the project's emphasis on hardware-focused engineering.

These design decisions reflect a hardware-oriented approach tailored to the team's electrical engineering expertise and a desire to produce a scalable, user-supervised hydroponics system that remains functional without heavy reliance on software or adaptive control.

Several constraints have directly influenced the design of the hydroponics system. The project is limited by a budget of $500, requiring that components be cost-effective, readily available, and sourced from reputable vendors. This constraint led to the selection of standard, off-the-shelf parts for power conversion, switching, and sensing, and discouraged reliance on proprietary or specialized components. Furthermore, thermal management and power efficiency presented critical constraints, especially for subsystems operating at higher currents, such as the LED array and peristaltic pumps. As a result, buck converters and MOSFET-based switching circuits were chosen to minimize heat dissipation and power loss.

Component availability has also influenced system design. All semiconductors, passives, and development tools were selected based on current stock levels from major suppliers, including Digi-Key and Mouser. In addition, the system is required to be modular, enabling individual subsystems—such as the power distribution board, sensor interface, or LED driver—to be replaced or updated without affecting the rest of the system.

Multiple DIY hydroponics systems were reviewed as references. Open-source projects built around Arduino and Raspberry Pi platforms were found to cover basic lighting and pump control using pre-programmed timers or simple user input. These systems often utilize modular sensors for pH and EC monitoring and display values via LCDs or serial consoles. Documentation for such projects is widely available.

In contrast, commercially available hydroponic automation systems—such as those from companies like Autogrow or Bluelab are typically proprietary. While product manuals and interface documentation are available, internal schematics, firmware details, and system integration information are rarely published. These commercial systems demonstrate market viability but offer limited insight for educational design replication or analysis.

Execution

Component Sourcing:

General Electronic Components:

These suppliers will be used for MOSFETs, microcontrollers, buck converters, passive components such as resistors, capacitors, and inductors, as well as PCB manufacturing materials. Digi-Key offers a wide selection of electronic components with fast shipping, Mouser Electronics is a reliable source for power electronics and embedded systems, and Newark serves as an alternative vendor for both circuit components and development boards.

Embedded Systems and Prototyping Modules:

For micro controller accessories, LCD screens, and sensor breakout boards, Adafruit provides high-quality modules suited for embedded systems and prototyping. SparkFun serves as an alternative source for various sensors, displays, and microcontrollers, ensuring that the necessary options are readily available.

Power Electronics & PCB Fabrication:

Custom power supply components, PCB fabrication, and assembly services can be sourced from JLCPCB, which offers low-cost PCB manufacturing and optional pick-and-place services. OSH Park provides high-quality PCB production suitable for prototyping, and PCBWay supports both fabrication and assembly, making it helpful for more complex board designs.

Hydroponics-Specific Components:

Specialized hydroponics suppliers will be utilized for peristaltic pumps, EC sensors, and water temperature sensors. Atlas Scientific offers high-accuracy water quality sensors, including EC probes. HydroBuilder meets the needs for peristaltic pumps and hydroponic automation equipment, and GrowersHouse serves as an alternative supplier for hydroponic control systems. For PVC tubing that will be used to circulate the water throughout the system, ¾” tubing from Home Depot will be the likely choice. For the water pump that will be used it will most likely be the 12 volt Drummond water pump sold at Harbor Freight.

Miscellaneous Hardware:

For wiring, connectors, enclosures, and general tools, Amazon remains a convenient choice to quickly source generic hardware and supplies, ensuring that all necessary pieces can be acquired in a timely manner.

Execution will consist of performing a series of tests to see if the project is performing as designed. This will consist of using a multimeter to check if the circuits are getting the proper voltage or current in certain places. Executing the project will consist of testing each stage of the project in order to make sure that the once assemble no components may get damaged. Another test may include executing the LCD screen to see if lights up and the interactive interface actually functions. A logic analyzer would be a good tool to test whether the correct digital signals are being sent to the LCD screen Testing whether the pump has the ability to deliver nutrients and water efficiently and effectively will be another test.

Teamwork

The success of the automated hydroponics system relies on the combined expertise of both team members, each bringing a strong foundation in electrical engineering principles, circuit design, and embedded systems development. The project is structured to leverage these skills while addressing any gaps through research, consultation, and hands-on learning.

Team Capabilities:

Both members of the team are experienced in analog and digital circuit design, power electronics, and embedded programming. Key areas of focus for the project include power electronics, where a custom power supply with a buck converter will be developed to provide efficient power distribution, as well as embedded systems, where both PWM control for LED drivers and MOSFET-based pump drivers will be turning on/off using a switch. Sensor integration will involve designing signal conditioning for electrical conductivity (EC) and temperature sensors to ensure accurate measurements, and PCB design and fabrication will be carried out using tools such as KiCad or Altium for circuit layout and JLCPCB or OSH Park for manufacturing. While the team possesses strong hardware skills, additional knowledge in hydroponics systems, sensor calibration, and advanced PCB manufacturing techniques will be required. These gaps will be addressed by consulting faculty, reviewing datasheets, and engaging with online resources. If needed, assistance from professors, industry professionals, or senior students with expertise in power electronics and embedded control systems will be sought.

Team Collaboration and Workflow:

The project will be guided by a structured approach aimed at sustaining momentum and ensuring thorough coverage of all tasks. Multiple weekly meetings will be conducted to review progress, identify and resolve any difficulties, and outline short-term objectives. Responsibilities will be divided between one member focusing on power supply and LED driver circuits, and the other concentrating on pump control and sensor integration. Shared circuit reviews and regular meetings will facilitate communication and maintain alignment between both members. Documentation and version control for schematics, PCB layouts, and firmware will be handled through GitHub or a similar platform to keep track of modifications, prevent conflicts, and promote an organized workflow.

Contingency Plan:

Should one team member be unable to continue because of unforeseen circumstances, the remaining member will first reassess the project scope to emphasize essential functionalities, including the power supply, LED driver, and pump control, while potentially simplifying less critical elements, such as UI expansion. If further support is necessary, faculty advisors, classmates, or other experienced engineers will be consulted for technical advice. Finally, any unfinished design work will be redistributed, with the remaining member taking on those responsibilities while leveraging all existing research and documentation to maintain continuity in the project.

Better Grade

To merit a higher grade, the team intends to expand the analog design challenges within the hydroponics system by incorporating advanced signal conditioning, calibration techniques, and analog-based environmental control. These additions will require detailed circuit design, repeated testing, and a strong understanding of noise reduction, sensor linearization, and power control—all beyond the level of standard laboratory exercises.

A key enhancement will involve the design, simulation, and tuning of analog signal conditioning circuits for the electrical conductivity (EC), pH, and temperature sensors. These circuits will include precision low-pass filters, differential amplifiers, and biasing networks to ensure accurate, low-noise measurements. Testing will involve validating signal linearity, minimizing offset and drift, and identifying environmental effects such as temperature sensitivity.

In addition, manual calibration procedures will be developed for the sensor circuits. Reference solutions and controlled temperature environments will be used to characterize sensor outputs and produce correction curves. These curves will be applied to fine-tune the analog front end, ensuring that measurements remain within acceptable error margins without relying on digital compensation.

An advanced analog feature planned for implementation is a temperature-based fan control circuit. Using a thermistor and analog comparator or op-amp configuration, a fan will be automatically activated when the ambient temperature exceeds a predefined threshold. This control loop will be fully analog, requiring no microcontroller involvement. The design will be refined to avoid false triggering, provide stable switching, and reduce power consumption.

These additional analog subsystems reflect a deeper commitment to electrical design rigor, system testing, and physical circuit optimization. By focusing on analog precision and environmental control through hardware alone, the project will demonstrate technical depth that justifies consideration for a higher academic grade.

Conclusion

The proposed automated hydroponics system is designed to create a self-regulating growth environment with a strong emphasis on electrical engineering principles. By integrating a custom power supply, precise PWM-controlled LED driver, and MOSFET-based pump driver, the system will ensure efficient energy use and reliable operation.

Real-time monitoring will be achieved through EC, pH, and temperature sensors, which will provide critical data for maintaining optimal nutrient levels. The micro-controller will serve as the control center, managing the sensors, sensor data, and making user interaction easy through an LCD display. The inclusion of an MCU serial server module will enhance system efficiency by improving communication and enabling remote monitoring capabilities.

While adhering to design constraints such as power efficiency, component availability, project difficulty and budget limitations, this project remains feasible within the allocated budget. By prioritizing hardware development and leveraging modular design principles, the system ensures scalability and adaptability for future enhancements. This project serves as a comprehensive application of power electronics, motor control, sensor processing, and embedded systems, resulting in a working hydroponics system.