Mushroom Incubator: All-in-one Automated Mushroom Growing Solution

Project Proposal
Senior Design
ECE 445

by
Team 6
Elizabeth Boyer, Cameron Fuller, Dylan Greenhagen

University of Illinois Urbana-Champaign
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1 Introduction

1.1 Problem:

Many people want to grow mushrooms in their own homes to experiment with safe cooking recipes, rather than relying on risky seasonal foraging, expensive trips to the store, or time and labor-intensive DIY growing methods. However, living in remote areas, specific environments, or not having the experience makes growing your own mushrooms difficult, as well as dangerous. Without proper conditions and set-up, there are fire, electrical, and health risks.

1.2 Solution:

We would like to build a mushroom incubator with humidity and temperature sensors that could monitor the internal temperature and humidity. Together, a heating element would supply heat to the unit and a misting system (and attached water tank) would provide humidity to the unit, both working continuously to regulate temperature and humidity. A ventilation and lighting system would provide positive and efficient growth conditions. There would be a visual interface to display the current temperature and humidity within the environment, as well as set the desired temperature and humidity. It would be medium-sized (around 2 sq ft) and able to grow several batches at a time, with more success and less risk than relying on a DIY mushroom tent.

Some solutions to home-grown mushroom automation already exist. However, there is not yet a solution that encompasses all problems we have outlined. Some solutions are too small of a scale, so they don't have the heating/cooling power for a larger scale solution[1]. Therefore, it's not enough to yield consistent batches. Additionally, there are solutions that give you a heater, a light set, and a humidifier, but it's up to the user to juggle all of these modules[2]. These can be difficult to balance and keep an eye on, but also dangerous if the user does not have experience. Spores can get released, heaters can overheat, and bacteria and mold can grow. Our solution offers an all-in-one, simple, user-friendly environment to bulk growing.

1.3 Visual Aid

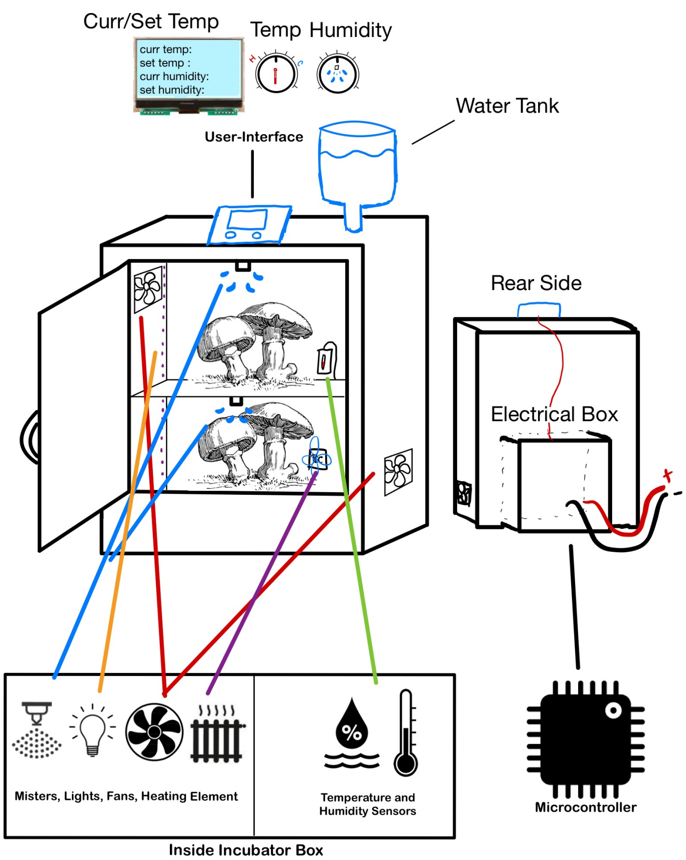

Figure 1.3.1: Visual Aid

1.4 High-Level Requirements List

Our demonstrable high-level requirements are as follows:

- For the control unit and user interface, we will demonstrate that the user can change the set temperature and humidity values through buttons or knobs, and the display will output the correct set temperature and current temperature within 10 seconds.
  - Ex.) If the user changes the set temperature to 80°F, the change in set and current temperature will be reflected on the display promptly, and can be verified independently.
- The humidity sensing and control system's functionality will demonstrate that introducing dry air into the device activates the misting system, which requires functional sensors and a water pump.
  - If the humidity sensor detects that the humidity is below the set point, the misting system will activate, allowing for an increase in the humidity at a rate of 1% every 2 minutes.
  - If the humidity in the chamber is too high, the fans will activate, reducing the humidity at a rate of 1% every 2 minutes.
- The temperature sensing and control system demo will show that the heater and fans respond appropriately:
  - If the measured temperature is above the set point, the heater turns off and the fans run at high speed, reducing the temperature towards the set point at a rate of at least 1 °F/ 1 minute (see Equations 2.4.5/2.4.6).
  - If the measured temperature is below the set point, heater turns on and the fans run at low speed, increasing the temperature towards the set point at a rate of at least 1°F / 1 minutes (see Equation 2.4.2).

- The air quality control system's success will be demonstrated as air movement coming from the fan enters the tent, passing through the filter, and exits the tent at a constant rate.
- The lighting system will turn on the lights at a set time of day, and then turn them off at a set time of day.

2
Design

2.1 Block Diagram

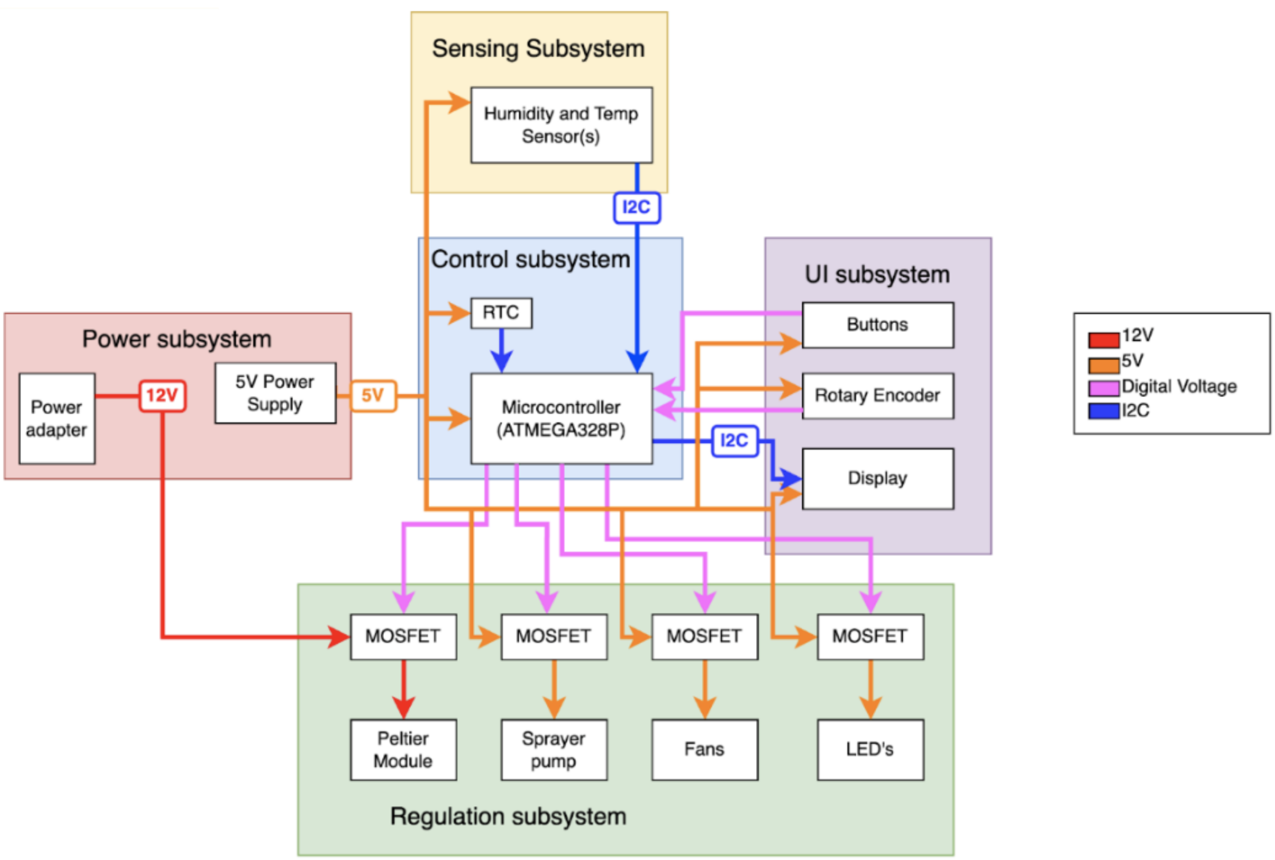

Figure 2.1.1: Block Diagram

2.2 Subsystem Overview

2.2.1 Sensing Subsystem:

The sensing subsystem is responsible for detecting the change in the temperature and humidity, and sending those signals to the microcontroller in the control subsystem via I2C. It is powered by the power subsystem.

2.2.2 Power Subsystem:

The power subsystem is responsible for providing and regulating the power sent to all the other subsystems. It supplies both a 12V and 5V current through the use of voltage regulators. 12V are sent to the MOSFET for the Peltier module, and 5V is sent to the sensing subsystem, the UI subsystem, and the MOSFETS for the sprayer pump, LED's, and fans in the regulation subsystem.

2.2.3 Control Subsystem:

The control subsystem deals with deciding the necessary temperature and humidity adjustments for each moment in time based on the signals sent to it from the sensing subsystem, and then changes the relevant digital voltage signals to the regulation system, namely the MOSFETs connected to the Peltier module, sprayer pump, fans, and LED's. Additionally, it sends information to the display through I2C regarding the current and set temperature and humidity, which it receives from the sensing subsystem. This system also features a Real-Time Clock (RTC) module, allowing the MCU to compare the actual time of day to the times set to turn the LED's on and off. The MCU will access this data using I2C.

2.2.4 Regulation Subsystem:

The regulation subsystem handles the actual adjustments that are made to keep the project working as intended based on the signals received from the rest of the system. It includes the Peltier module, sprayer pump, fans, LED's, and their respective MOSFET's. It receives 12V and 5V from the power subsystem, and digital voltage signals from the control subsystem in order to control the heating and humidity elements.

2.2.5 UI Subsystem:

The UI subsystem displays information about the current and set heating and humidity levels (switching between them by pressing the buttons), and allows the user to change the settings via rotary encoders. The buttons and rotary encoders communicate with the control subsystem via digital voltage, and in turn receives I2C data from the control subsystem about what to display.

2.3 Subsystem Requirements

2.3.1 Sensing Subsystem Requirements:

This subsystem senses the temperature and humidity inside the enclosure, and sends it to the control subsystem. The sensors must both be able to withstand a temperature of 70-85°F and a humidity between 70-95% for prolonged periods. It must be supplied 5V +/- 0.5V at .98mA.

2.3.2 Power Subsystem Requirements:

This subsystem supplies the necessary power for the other subsystems in our design. A 12V wall adapter will be used for the Peltier module, and a 5V switching power supply will power the fans, sprayer pump, MCU, RTC, sensors, rotary encoder, LED's, and display. The 12V adapter will need to source 12V +/- 0.3V at 5 amps, and the 5V power supply converter will need to source 5V +/- 0.3V at a maximum of 3.6 amps.

2.3.3 Control Subsystem Requirements:

This subsystem controls the other subsystems using a microcontroller. In our design, it requires a supply voltage 5V +/- 0.5V at 10mA.

2.3.4 Regulation Subsystem Requirements:

This subsystem creates the regulation of our temperature and humidity values through a misting system, fans, as well as a Peltier heating module, and also provides illumination from LED's. For our misting system, we can output a maximum of 1.02L/min from 5V +/- 0.5V of input voltage provided by the power supply. Our fans operate at a maximum of 3400 RPM with a voltage input of 5V +/- 0.1 from our power supply system. The LED's require 5V +/- 0.2V at up to 2.4A. Finally, the heating Peltier module will operate at a maximum voltage of 12V +/- 0.5 at up to 4A from our power supply.

2.3.5 UI Subsystem Requirements:

This subsystem allows the user to interact with the control subsystem by turning knobs to change the set temperature and humidity. The display requires 3.3V +/- .2V at 50mA, which can be achieved with an input of 5V by using a 5V-3.3V converter.

2.4 Tolerance Analysis

For most mushrooms, ideal growing temperatures are roughly in the range of 75-80°F. Anything past 83°F begins to lower the return and growth rate. For this reason, our temperature tolerance must be at or less than $\pm$3°F to ensure that even at the highest temp we will use(roughly 80°F) there is no drop in growth quality. In terms of humidity, while the best amount varies based on the type of mushroom, the general rule is to stay between 75% and 90%. Any lower than roughly 70% and the mushroom will begin to dry out, and any higher than 95% will cause the caps to yellow or brown. For both of these reasons, the humidity tolerance will need to be at worst $\pm$5% humidity, to ensure the optimal growing environment even at the extremes of our values.

Electrically, for our buck converter (the N7805-1PV)[4], we will be dropping from 12V to 5V at maximum 1A based on the preliminary parts list. With this in mind,

$$
\begin{gathered}
P_{in} = P_{out} + P_{heat} \\
P_{out} = V * I \rightarrow P_{out} = 5 * 1A = 35W \\
P_{in} = P_{out}/efficiency \rightarrow P_{in} = 35W/81\% = 43.21W \\
P_{heat} = P_{in} - P_{out} = 43.21W - 35W = 8.21W
\end{gathered}
\tag{2.4.1}
$$

This will leave us with a heat dissipation of 8.21W or 29.56kJ/h.

2.4.1 Heating Time Calculations

- Air at room temp: c = 1005 J/kg * K (note: the specific heat of water vapor in humid air is negligible)
- Volume of the inside of our container: 0.061 cubic meters
- Density of room temp and pressure air: 1.204 kg/ cubic meter

  Therefore mass of air: 0.073 kg

At $\Delta T = 1K$:

$$
\begin{gathered}
Q = mc\Delta T \\
mc\Delta T = 0.073 * 1005 * 1 = 73.4J
\end{gathered}
\tag{2.4.2}
$$

Our Peltier module can reasonably supply 10 J/s (max is 20), so this is about 7.3 seconds to raise all of the air in the container by $1°C$ or $1.8°F$, or just under 4 seconds to raise by $1°F$. To account for ramp-up time, convection, and air replacement, we estimate 2 minutes to raise by $2°F$. This is reasonably adequate for the requirements of our application.

2.4.2 Cooling Time Calculations

One of the uses of our fan system is to cool the inside of the incubator, using the room temperature and the fact that the inside of the incubator has a high humidity.

First, we consider the ambient cooling byproduct of the ventilation system:

- At a 30% duty cycle, fan RPM: 1400
- Cross-sectional area of the fan: 0.0064 m^2
- Q = Volumetric Flow Rate

$$\begin{gathered}Q = A * V \\ Q = A * (2 * \pi * r * RPM)/60 \\ Q = .0064 * (2 * pi * .80 * 1400)/60 \\ Q = .075 m^3/\text{ minute}\end{gathered} \tag{2.4.3}$$

Now, we find how long it takes this volumetric flow rate of fresh air to fill the incubator, and the current air to leave:

$$\begin{gathered}(\frac{.075m^3}{1\text{ minute}} * \frac{1}{.061m^3})^{-1} \\ = 0.8133\text{ minutes, or 48 seconds to cycle all air}\end{gathered} \tag{2.4.4}$$

Therefore, our fans will be displacing the air from the incubator to its environment at an upper bound of every 5 minutes. Due to our heating calculations, this should be balanced by our heating unit.

Second, we consider the active cooling when we want to vent warm air and bring in room temperature (70°F) air:

- At a 100% duty cycle, fan RPM: 3400
- Cross-sectional area of the fan: 0.0064 m^2
- Q = Volumetric Flow Rate

$$\begin{gathered}Q = A * V \\ Q = A * (2 * \pi * r * RPM)/60 \\ Q = .0064 * (2 * pi * .80 * 3400)/60 \\ Q = 1.823 m^3/\text{ minute}\end{gathered} \tag{2.4.5}$$

Now, we find how long it takes this volumetric flow rate of fresh air to fill the incubator, and the current air to leave:

$$\begin{aligned}
&(\frac{1.823m^3}{1 \text{ minute}} * \frac{1}{.061m^3})^{-1} \\
&= 0.033 \text{ minutes, or 2 seconds to cycle all air}
\end{aligned} \tag{2.4.6}$$

Therefore, we want to allow an achievable upper bound of 1 minute to decrease the temperature by 1°F when ran at room temperature.

2.5 Ethics and Safety

In relation to the IEEE Code of Ethics:

- We must comply with ethical design and sustainable development practices and disclose factors that might endanger the public or environment. In relation to our project, our growing environment must not in any way harm the surrounding environment.

- Since there is a group doing something similar in terms of measuring values relating to plants (they are measuring moisture values), we must make sure all our ideas are our own and original.

- We must make sure all our claims and estimates are accurate and realistic, and accept honest feedback and criticism from our TA to make our project as precise as possible.

- We must credit any sources, code, data, or information we use in the process of making our project.

- We must use any equipment only if trained or experienced to use them.

- We must work well with our team, and treat each other fairly and with respect.

Additionally, we do not condone the use of our produce for the purposes of growing illegal substances as stated by US federal regulations.

For safety concerns:

- Make sure safety protocols are followed while in the lab soldering, using our PCB, and testing our sensors.
- Make sure to be aware when something can put ourselves at risk (when testing and building).
- Set boundaries, and make sure to work collaboratively so that not one person is more at risk for injury than another.
- Make sure that the end-product is safe and does not harm the user of the device, the environment, and the public.

Bibliography

[1] Shrooly, *"Grow mushrooms you can't find anywhere"*, https:// shrooly.com/#faq. (Accessed Feb. 8, 2024).

[2] Midwest Grow Kits, *"Ultimate Mushroom Growing & Incubator kit"*, https://www.midwestgrowkits.com/Ultimate-Mushroom-Growing-and-Incubator-Kit. (Accessed Feb. 8, 2024).

[3] Microchip Technology, *"ATMEGA328PB Datasheet"*, https://www.microchip.com/en-us/product/atmega328pb. (Accessed Feb. 9, 2024).

[4] Cui Inc. — Mouser, *"VGS-35C-15"*, https://www.mouser.com/datasheet/2/670/vgs_35w-2474743.pdf. (Accessed Feb. 21, 2024).

[5] Ethan Bloch, *Bard tex style files*, https://faculty.bard.edu/bloch/tex/. (Accessed Feb. 19, 2024).