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Manufacturing mycelium moulds under controlled conditions using IoT

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ABSTRACT

In the process of making plastics, potentially dangerous substances like colourants or stabilisers are added. One example is phthalates, which are used to make PVC. The ecology is significantly impacted by the way plastic products are disposed of as well. The majority of plastics can take a long time to biodegrade lengthy time to break down if disposed of in a landfill. The issue of plastic trash is getting worse. Plastic is incredibly valuable due to its cheap availability and low cost of production; however, its recyclability has been oversold. Mycelium mould is a fantastic substitute for plastic. Mycelium is more efficient in terms of biodegradability and sustainability compared to plastic. The properties of Mycelium include heat insulation, fire resistance, water resistant, acoustic insulation, low weight, vegan meat, beauty products, and mainly bio-degradable. All these features make mycelium our only last chance to win the war against the plastic with greater potential than the other alternatives for plastics available in the market currently. Here, we have shown how mycelium can be grown in the most efficient way ever without any contamination and faster growth cycle. The primary goal is to lower the cost of mycelium mould, lessen mycelium spoiling, and accelerate its growth cycle by offering an ideal growing.

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1. INTRODUCTION

Plastic takes 400-1,000 years to naturally break down, and some types of plastic never decompose. Plastic clogs waterways, oceans, seas and lakes. Many creatures perish after consuming plastic, and one in three species of marine mammals have been discovered entangled in marine garbage [1]. The stomachs of almost 90% of seabirds contain plastic trash. Packaging frequently uses plastic. Consuming food in plastic containers can lead to cancer. and the list goes on what if there is an alternative solution for the plastic crisis which has the potential to replace plastics to a greater extent and unlike the other alternatives this is even cheaper than plastic, it is called the mycelium root like structure of the fungus. A large quantity of branched fibers that comprise a mushroom is called mycelium. It is a robust, safe, biodegradable substance with many applications. In contrast to plastics and other synthetic materials may take hundreds of years to decompose, mycelium-based products naturally decompose after their product cycle. Together with environmental advantages like reduced emissions and improved land use, these more sustainable products may also contribute to the development of a circular economy. This mycelium can be cultured under certain specific conditions to grow a mould of any desired size and shape [2]. These cultured moulds have a numerous applications such as building bricks, packaging materials, and, insulating boards our project is a miniature of a mycelium mould manufacturing unit that can be controlled by a mobile app. It seems that mycelium needs certain climate conditions (temperature and humidity) [3] where it can thrive and grow multiple times faster than it regularly grows outside in woods i.e. controlled temperature and humidity.

We have developed an idea of making a climate controlled environment using thermal resistant structures, internet of things (IoT) [4] and sensors [5]. To achieve the desired climate we need a thermal resistant structure where the climate that we simulate inside the pod must not be influenced by the outside climate. To achieve this we have used acrylate sheets and slotted L-angle for the framing purpose and PU foam which act as a heat insulation layer [6]. PU foam are generally used for the insulation purpose in US Homes. In order to achieve heating and cooling we can use Peltier device, using the temperature differentials across the ends, we can use this along with heat sinks and CPU cooler fans to increase the efficiency [7] of the Peltier device and use it to the fullest, either as cooler or heater, for dehumidification, we use the natural process of condensation by passing the internal air on a cooler surface and condensing it to liquid water and removing it. For the humidification we can use piezoelectric humidifier which instantly converts liquid water to vapor by vibrating in a particular frequency.

2. RELATED WORK

By altering the nutritional makeup of crops, pulsed electric field (PEF) technology [8] may increase agricultural output and growth. It was examined how well the pleurotus ostreatus white oyster mushroom species responded to PEF therapy. Monopolar pulses with an amplitude of roughly 20 kV were used to excite the mushroom sawdust substrate in buckets [9]. Rod-plate electrode designs, characterized by peak electric field strengths of 1.46 and 6.67 kV/cm were used. Over the course of 30 days, 62.3 kJ (0.017 kWh) of electrical energy was delivered to each mushroom bucket. In comparison to the control group, the stimulated group’s overall yield [10] rose by 34%. The stimulated buckets [10], [11] generated 45.5% more than the control in a repeat of the experiment. Following stimulation, measurements were made of the fruiting bodies’ ash, protein, fat, and moisture content. The stimulated group’s mean crude fat and protein content is marginally higher than that of the control group [12]. Furthermore, it was discovered that a 10% increase in ash content above the control group was caused by the interface between the fruit substrate and the ground mesh electrode [13].

The technology used in mushroom farming provides a framework for monitoring and managing the growth of mushrooms. The subject of this analysis was the oyster mushroom [14]–[16]. Oyster mushroom development is measured using real-world variables including stickiness and temperature [17]. The ideal growing conditions for oyster mushrooms are temperatures below 29 °C and relative humidity levels between 80 and 90% (RH). The amount of light required for development should not exceed 300 lux. The goal of this test is to provide a device that can regulate the temperature and mugginess organically via fluffy reasoning control [18]. Regarding the actual light, it employs an LDR sensor capable of activating the driven lights if the light level exceeds 300 lux. The actuator is a water syphon and fan, and the sensor is the DHT11, which monitors temperature and moisture content. To boost the amount of clam mushroom harvests, this framework monitors and regulates temperature and humidity in oyster mushroom hatcheries. Temperature and humidity are measured using a node MCU that is linked to an online worker, which can be accessed via an Android application [19]. Use RTC to change the watering time. As a developing country, agriculture is most of the Sri Lankan economy. Cultivation of fungi is a popular option for low-space farmers and time required for culture, but high nutrition. However, because of the drawbacks and inefficiency of the current manual methods, the majority of farmers are unable to obtain the highest yield from their crop. This article aims to prevent inefficiencies in the mushroom farming process by using an ICT solution. One of the most common mushrooms, oyster mushrooms, serve as the foundation for the system. For precise mushroom cultivation, it has four features: a yield prediction feature built with long and short-term memory (LSTM); a convolutional neural network (CNN) and Mobile Net V2 model for harvest timing; a disease detection and control recommendation feature built with CNN and Mobile Net V2; and an environmental monitoring feature built with LSTM [20]. The system has a 92% accuracy rate in determining harvest time and an 89% accuracy rate in monitoring environmental conditions. Furthermore, the system has a 99% accuracy rate in detecting fungal infections and a 97% accuracy rate in forecasting monthly mushroom production. Additionally, the system detects fungal diseases with 99% accuracy and predicts monthly mushroom yields with 97% accuracy. Intensive use of precision agriculture will ultimately lead to increased mushroom yields.

Most Malaysian farmers rely solely on traditional farming practices. However, modern agricultural technologies have proven superior to traditional practices in increasing farm efficiency and productivity [21]. The IoT is often associated with modern agriculture as it allows farmers to monitor the condition of their farms in real time, from anywhere, anytime [22]. Oyster mushrooms are currently one of the most widely produced crops in Malaysia.

Nevertheless, the conventional growing method, which is more costly, less productive, and requires more upkeep, continues to eclipse it. Consequently, the main motive of this growing method is to develop an inexpensive automated climate control system that can optimise resources and regulate the farm's condition [23], [24]. At NASOM Bandar Puteri Centre, our suggested IoT-based project was put to the test in real-world settings. Temperatures between 20 and 30 °C and humidity levels between 70 and 80% are ideal for oyster mushroom growth. To detect temperature and humidity, two sensors have to be placed in the centre of the mushroom hut and at its corners. A microcontroller unit then sent the data to a remote monitoring station, which took additional action [25]. The six-day trial resulted in an effective automated monitoring system that can monitor farms while minimizing resources and human effort. From the existing system, the various key drawbacks are analyzed such as low yields due to traditional method. Traditional approach leads to higher operational costs. In modern approach previous production yield technique like PEF technology yields high energy consumption.

3. PROPOSED APPROACH

The suggested system created here is not like any previous literature work that has been done before. The climate control pod mimics a variety of climatic conditions that impact mycelium development by utilising the IoT, many sensors, and specific physics concepts. In the suggested system, we have implemented a number of modules. Everything is assembled, monitored and controlled using microcontroller and mobile application, architecture of proposed work is shown in Figure 1. Figure 2 displays the proposed approach's flowchart. It shows the sensor integration for temperature and humidity measure and also indicates the thermal resistant structure for manufacturing mycelium moulds.

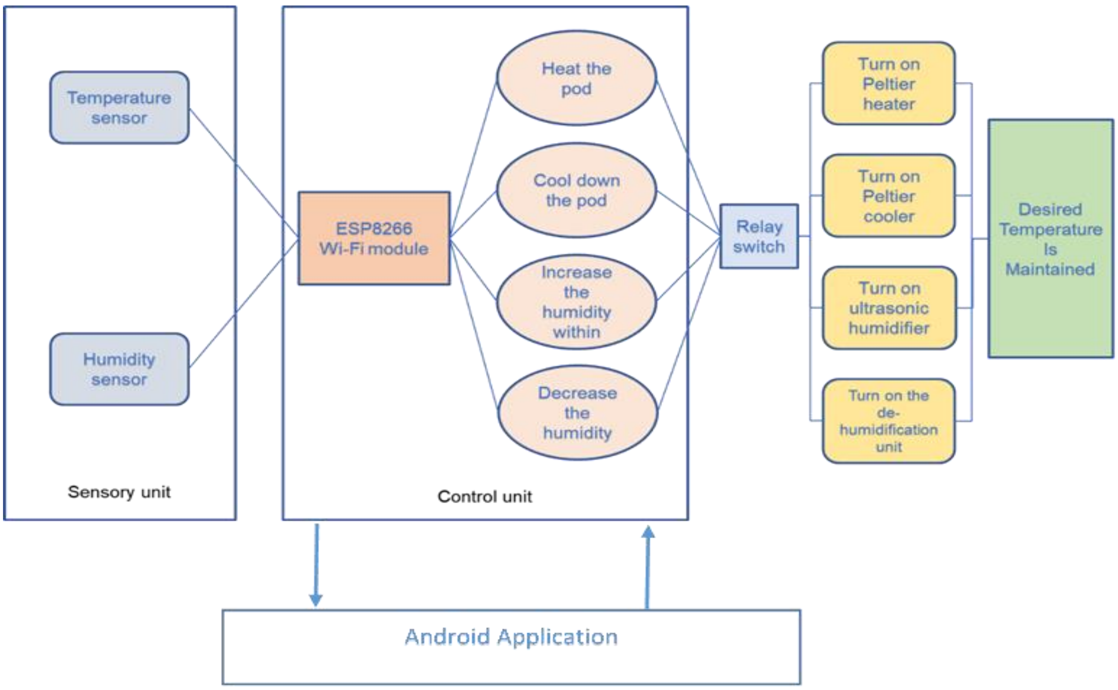

Figure 1. Architecture of the proposed approach

3.1. DHT11–temperature and humidity sensor

This sensor is used in this module to check the temperature and humidity every second and to provide real-time data to the ESP8266 development board. A reasonably priced digital sensor for determining humidity and temperature is the DHT11. This sensor is easy to integrate with microcontrollers such as the Arduino and Raspberry Pi. to provide real-time temperature and humidity monitoring. With a 2-degree precision, the DHT11 can identify temperatures ranging from 0 to 50 degrees celsius. This sensor can identify humidity levels between 20 and 80% with a 5% accuracy rate. This sensor has a sampling rate of 1 Hz or 1 Hz. One measurement is provided per second. DHT11 has an operating voltage and is tiny in Figure 3.

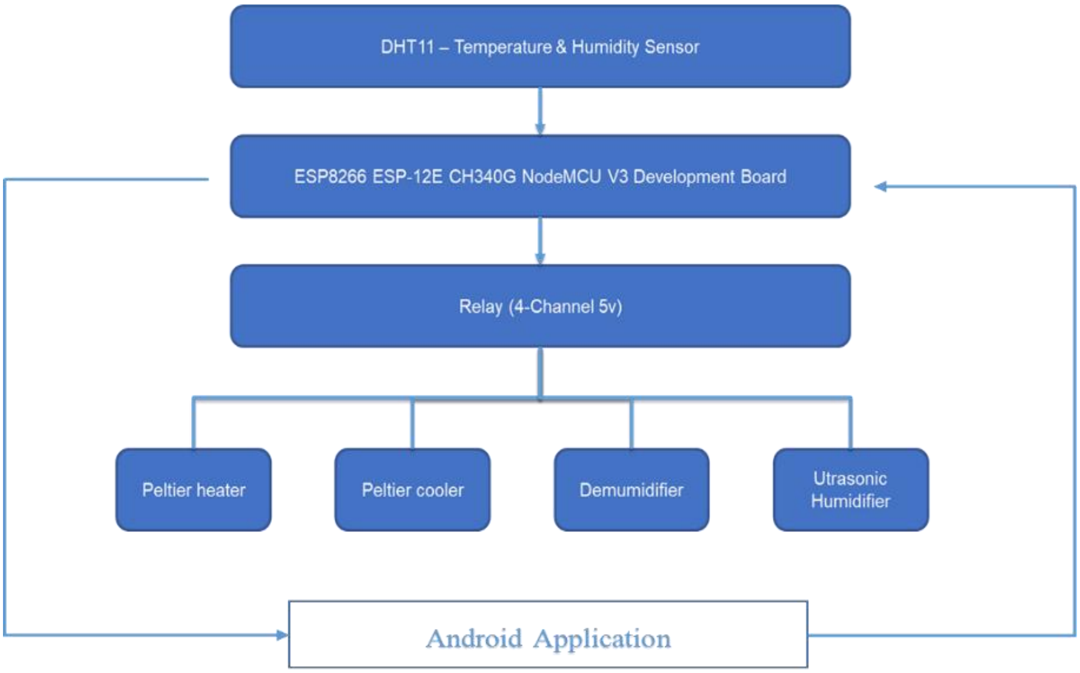

Figure 2. Flowchart of proposed work

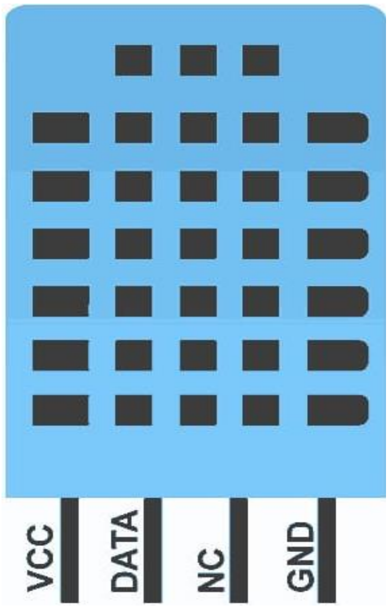

Figure 3. PIN diagram of the DHT11

3.2. ESP8266 ESP-12E CH340G NodeMCU V3 development board

In order to maintain the correct temperature and humidity specified in the mobile app, this unit regulates when to turn on and off each of the system's four modules. Additionally, because it is a WI-FI module, data is sent and received via the internet. The NodeMCU V3 is an open-source ESP8266 development kit that works with breadboards and has the CH340G USB TTL serial chip. The CH340 chip line is seen as a more affordable substitute for the CP210x. For industrial applications, CH340 is not only incredibly dependable but also reasonably priced. Additionally, all supported platforms have been used to assess its stability. It is simple to use with the Arduino IDE and NodeMCU Lua thanks to its integrated USB connectivity. One of the most extensively used development boards on the internet is the ESP8266 NodeMCU. It is based on the ESP12E Wi-Fi module and functions flawlessly when combined with Wi-Fi features and simple programming using the Arduino IDE. The integrated programmer and the CH340G USB-to-serial chip, which flashes the serial output with the ESP8266's PC integration, make prototyping and development projects simple.

Additionally, the ESP8266 NodeMCU development board contains multiple crucial components on a single board, similar to the Arduino board. ADC, GPIO pins, voltage regulators, a tiny USB connector, and a number of additional components are visible. Crucially, the ESP8266 has complete Wi-Fi capability, enabling Wi-Fi connection with a server or client. Additionally, the device is a system on a chip (SoC) produced by espressif, a Chinese company. The ESP8266 NodeMCU board's 11 GPIO ports and analogue input are additional crucial features. Last but not least, it can be programmed similarly to an Arduino or other microcontroller. The development board provides numerous forms of help for connectivity. By joining a Wi-Fi network, it enables Wi-Fi connection and lets you host a web server with an actual website. Additionally, you can link your smartphone. As a result, this chip has grown significantly and is now the most widely used IoT gadget available. Its CPU, RAM, and 32-bit low-power ROM are all integrated. Software programs can operate as a stand-alone device thanks to the standalone Wi-Fi spectrum solution. The PIN diagram for the ESP8266 is shown in Figure 4.

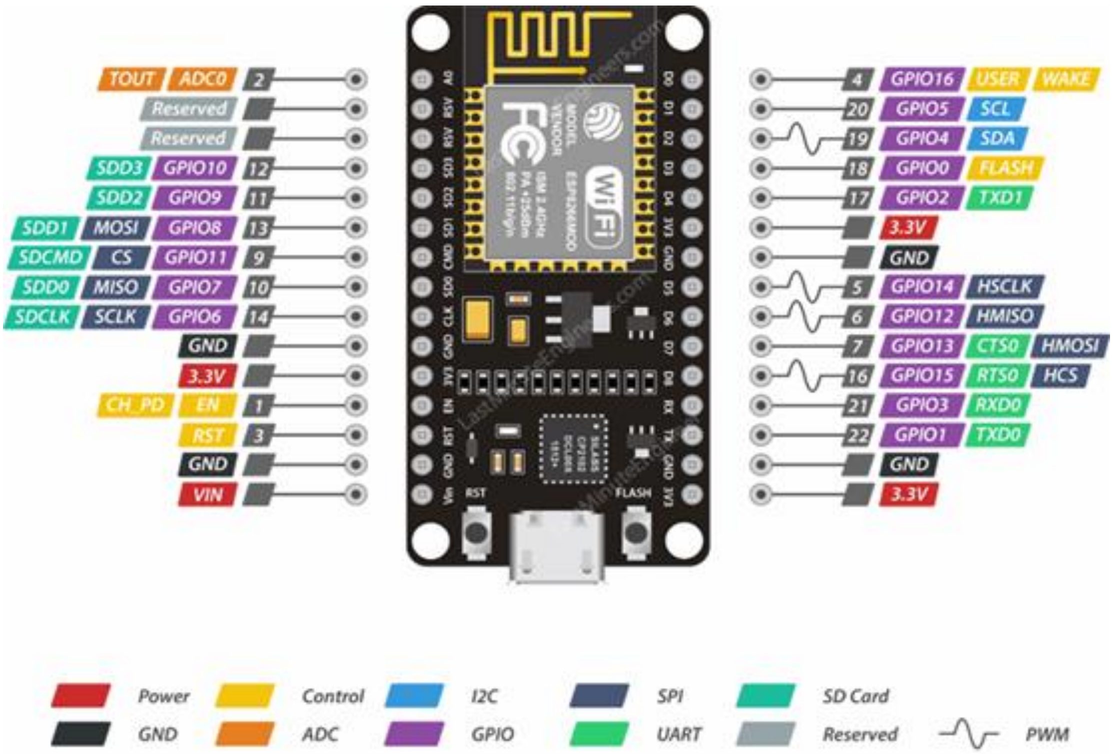

Figure 4. PIN diagram of ESP8266

3.3. Working of relay

Relays are similar to switches which are operated both mechanically and electrically. A relay consists of components such as an electromagnet and a set of contacts. Relays are mostly employed in situations when a circuit can only be controlled by a low-power signal. Additionally, it is employed in locations where a single signal can be used to manage numerous circuits. They served as a means of switching the signal from its source to its destination. High power is needed for the electric motors to drive the high-end relay applications. We refer to these relays as contactors. An isolation circuit, a power supply, and a driver circuit make up a relay board configuration. Transistors are used in the driver circuit to perform the switching function. The relays are switched by transistors. An isolation circuit shields the controller and transistor from harm by preventing the relay from generating reverse voltage. The microcontroller unit providing the input pulse necessary to switch the transistor. It works on 5V direct current provided as an input voltage. The 4-channel relay as shown in Figure 5, is being used has four switches which receives the command from the Node MCU, to switch on and off the four temperature and humidity control units.

3.4. Developing Heater and cooler using Peltier module

As shown in the Figure 6, Two different kinds of semiconductor components are positioned in tandem between copper substrates in the Peltier module configuration. One element's electrons and the other element's holes move when current passes through the module. We refer to this as the "Peltier effect." As a result, depending on the direction of the current, the substrate can alternate between hot and cold sides, with one side absorbing heat and the other radiating it. By employing the "Seebeck effect," which occurs when a temperature differential is applied to both sides of the Peltier module, current flows, it may also be utilised as a thermoelectric power production module.

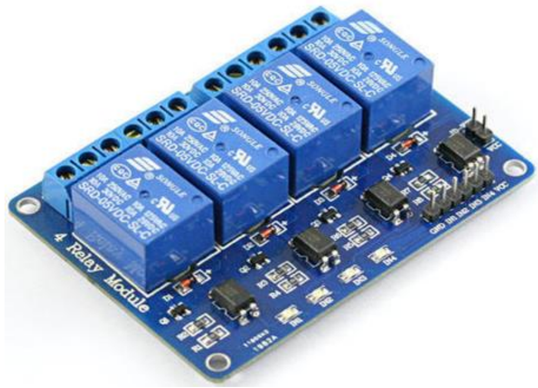

Figure 5. Relay (4-channel)

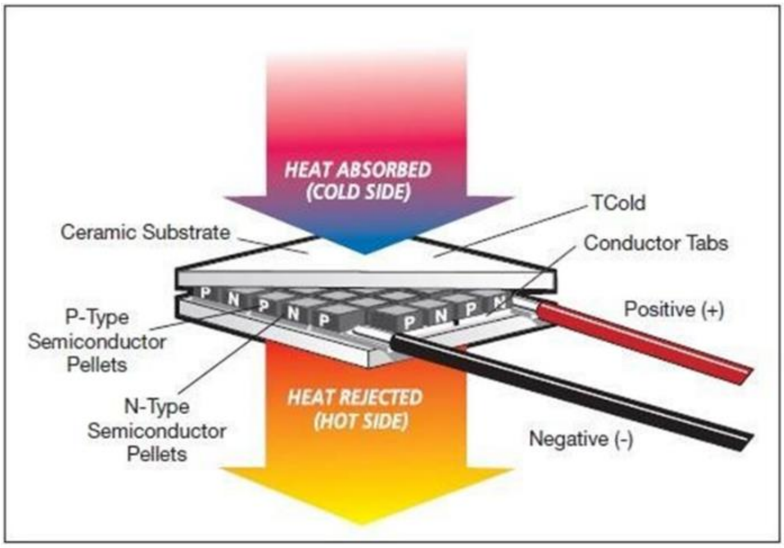

Figure 6. Peltier module

When a voltage is applied between two connected conductors, an electric current is generated. When current flows through the conductor connection, heat is dissipated on one side and released on the other. As a result, one side experiences cooling, while the other side experiences heating. By connecting a heat sink to the hot side, heat may be quickly dissipated (making it suitable for use as a heater) and the TEC's hot side can stay around room temperature. Conversely, the chilly side can achieve temperatures lower than ambient temperature (thus can be used as a cooler), so we have can develop both heater and cooler using Peltier module.

3.5. Working principle of piezoelectric ultrasonic humidifier

As shown in Figure 7, this DC 5V power board is suitable for 20 mm diameter atomization plate tablet atomization chip ultrasonic humidifier and moisture membrane humidification atomizer. This piezoelectric transmission module for ultrasonic humidifiers makes use of the sound wave cavitation theory.

It may be turned into a tiny ultrasonic atomiser by just providing DC3–12V electricity due to the compression and rarefaction found in sound waves. The water droplets travel so swiftly that they are unable to hold their liquid condition and will soon transform into steam. The piezoelectric filament is what causes this vibration. By rapidly turning liquid water into steam, the piezoelectric ultrasonic humidifier module enables you to raise humidity levels.

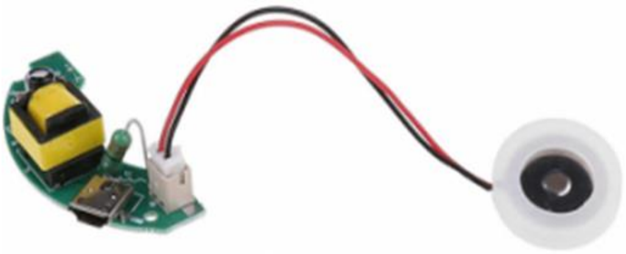

Figure 7. Piezoelectric ultrasonic humidifier

3.6. Condensation

Condensation is the phenomenon through which water vapor transforms into liquid. It is the reverse process of evaporation, which turns liquid water into vapour. There are two possible outcomes for condensation: either the air cools to its dew point or it gets fully saturated with water vapour that it can no longer hold any additional water vapour. (Condensation is the atmospheric transformation of water vapour into liquid). Temperatures can naturally drop below the dew point at night, which is why, as Figure 8 shows, you frequently find water droplets covering your house, car, and grass in the morning. Furthermore, water droplets may form on the outside of a soda can or a cold glass of water as a result of condensation. Water droplets form on the glass or can when warm air hits its dew point and condenses upon coming into contact with a cool surface. Any moisture in the air condenses into liquid water when air inside a container passes over a surface that is colder than room temperature, thereby eliminating humidity from the surrounding air.

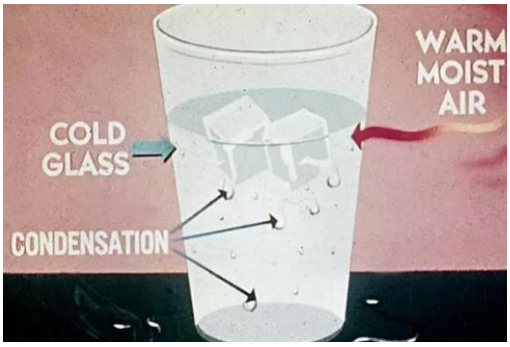

Figure 8. Condensation

3.7. Mobile application

The entire system can be monitored and controlled using a mobile application developed using the Blynk platform. In the mobile application we can set the desired temperatures and humidity, also monitor the system (like heater, cooler, and dehumidification) which is currently active and a graph representing the live values of temperature and humidity is also displayed for a better visual experience. The CSV files can also be downloaded for the temperature and humidity.

3.8. Thermal resistant structure

To achieve the desired climate we need a thermal resistant structure where the climate that we simulate inside the pod must not be influenced by the outside climate. To achieve this we have used acrylate sheets and slotted L-angle for the framing purpose and PU foam as a layer between the acrylate sheets, which act as a heat insulation layer. PU foam are generally used for the insulation purpose in Homes in cold regions. The entire modules are embedded within this structure to get the desired result as shown in Figure 9.

In this thermal resistant structure, acrylate sheet is chosen because it offers better thermal resistance than glass. It helps reduce heat transfer between inside and outside of the pod provides the thermal stability. Some other materials for thermal inclusion include polycarbonate sheets, FRP panels, insulated metal panels.

Figure 9. Thermal resistant structure with all the above mentioned systems embedded within

4. RESULT

By using the Peltier along with heat sinks and the CPU cooling fans we can easily increase and decrease the temperature. DHT11 sensors send the temperature and humidity in real time which is later processed using 'NodeMCU ESP8266' and 'blynk' we can automate the entire climate and humidity control We can set the desired temperature and humidity using the app we have developed using blynk which is embedded with the microcontroller. The dehumidification removes the water vapor i.e. condenses it to liquid water similar to the rain. Piezo-electric humidifier converts the water instantaneously to water vapor thus increasing the humidity with all the above said principles and methods we can now successfully mimic a wide range of climate and monitor it using a mobile application with all the modules and sensors integrated as shown in Figure 10. Due to the integration of all these, mycelium growth time reduced by 20-40% when compared to traditional methods. The integrated system is under monitoring and controlled by using the Mobile App Blynk in Figure 11 to monitor the temperature and humidity of the system.

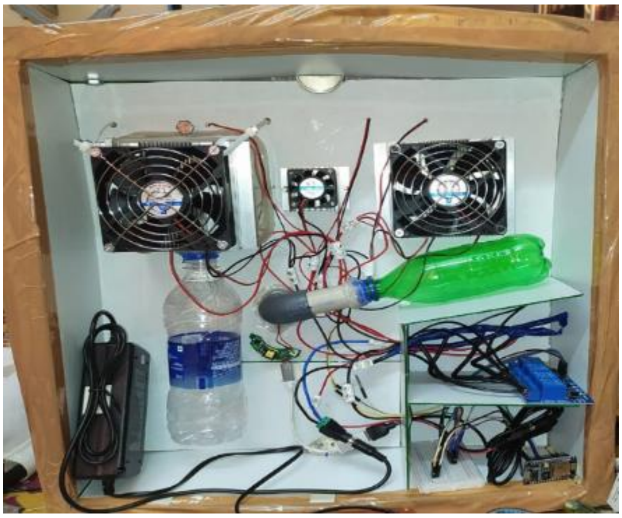

Figure 10. Modules and sensor integration

Figure 11. Mobile app result which shows the temperature and humidity

5. CONCLUSION AND FUTURE WORK

In this work, as an alternative for plastics, we have highlighted an effective way of growing mycelium without human intervention, which has the potential benefit of replacing plastics. and also cheaper to produce than plastics. With all the above said principles and methods we can now successfully mimic a wide range of climate and grow mycelium in the most efficient way ever without any contamination and faster growth cycle. This can be scaled and actually grow mycelium in commercial scale. Instead of using the Peltier for climate control we can actually use the air conditioning systems for climate control. An additional factor can also be included i.e., CO_2 level monitoring and control system which can give an edge in controlling mycelium's growth even better. But this method may affect the growth rate, if there is no continuous stable power supply and no proper maintenance of the system. Can be expanded to may fields other than packaging like leather, acoustic protection, heat-insulation, and vegan meat.

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AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

The authors confirm that the data supporting the findings of this study are available within the article.

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