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DELVING INTO ACCURATE LIGHT INTENSITY ANALYSIS ACROSS DIVERSE PARAMETERS IN HYDROPONIC SETTINGS USING MACHINE LEARNING

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Abstract

The study focuses on hydroponic gardens, which are highly regarded for their sustainability and precision. on important growth characteristics such as light intensity, temperature, pH level, plant height, leaf weight, number of leaves, stem growth, and light quality using four distinct colours of LED light (red, white, green, and blue). Analyzing the effect Oneness is ensured by stringent control with LEDs set for continuous intensity and extended exposure times. Monitoring the nutrition solution's steady pH and temperature improves accuracy. The development of hydroponic plants is affected differently by the hues of LEDs, according to preliminary studies. While blue light increases leaf weight and compactness, red light encourages vertical development, and diffused white light establishes equilibrium, green light has the ability to adjust pH levels. More significant than energy is spectral organization. Convolutional neural networks (CNNs), principal component analysis (PCA), clustering algorithms, predictive modelling, and other methods related to deep learning and machine learning are still in their infancy, according to research researchers. By fostering sustainable agricultural practices, these contribute to the goals of food security and environmental preservation by offering a deeper understanding of the intricate relationship between LED colour and plant growth. This understanding facilitates the development of specialized agricultural techniques that boost energy and productivity.

Keywords: Color, CSV, Hydroponic, LED

1. Introduction

Hydroponics, an ancient and innovative method of cultivating plants without traditional soil, finds its roots in the Hanging Gardens of Babylon, built around 600 BC in Mesopotamia. These gardens are considered one of the earliest examples of hydroponic horticulture, showcasing human ingenuity in delivering water and nutrients to plants in arid environments. Modern hydroponics has revolutionized agriculture by replacing soil with precisely calibrated nutrient solutions. This soilless approach accelerates growth, increases yields, and offers fine-tuned control over environmental conditions. Systems like Deep Water Culture, Nutrient Film Technique, Drip Systems, and Aeroponics cater to various plant species and developmental stages. At the core of hydroponics lies the nutrient solution, a balanced mixture of water and essential nutrients ensuring robust plant growth.

Monitoring and adjusting pH levels and electrical conductivity are crucial for optimal nutrient absorption. In controlled indoor environments, artificial lighting, such as LED grow lights, provides the necessary energy for photosynthesis. Hydroponic systems demonstrate remarkable versatility, excelling in growing crops like leafy greens, herbs, tomatoes, cucumbers, and strawberries. This adaptability makes hydroponics a sustainable and innovative facet of contemporary agriculture, capable of increasing food production while reducing ecological footprints. LED lights are indispensable in hydroponics, with different spectra serving distinct growth phases. Red LEDs, in the 600-700 nanometre range, enhance flowering and fruiting, resulting in higher yields and improved quality. Blue LEDs, emitting light in the 400-500 nanometre range, stimulate chlorophyll synthesis during vegetative growth, promoting robust foliage. Full-spectrum LED lights mimic natural sunlight and support overall healthy growth. Green LEDs, though less common, have specific roles. They penetrate deeper into plant canopies, promoting lower leaf photosynthesis and optimizing plant spacing and canopy management. Incorporating green light enhances light distribution, fostering healthier and more uniformly developed plants. Hydroponics continually explores innovative lighting solutions, including custom light spectra for specific growth stages. Combinations of red and blue LEDs create purple light, invigorating both vegetative and reproductive phases. Beyond the visible spectrum, research into ultraviolet (UV) and far-red light is ongoing. UV light can enhance flavour and nutrient content by stimulating secondary metabolite production, while far-red light influences plant height, internode length, and flowering periods. Energy efficiency is a top priority in hydroponics. LED technology has evolved to reduce electricity consumption while maintaining luminous intensity. Sustainable lighting systems are essential, especially for large-scale hydroponic operations. Automation and data analytics play vital roles in managing light efficiently. Smart controllers and sensors monitor plant responses to light conditions, enabling real-time adjustments and conserving resources. Machine learning (ML) and deep learning (DL) have transformed hydroponic agriculture. ML algorithms predict plant growth trajectories, detect anomalies, and optimize resource allocation, resulting in improved yields and resource management. DL techniques enable intelligent control systems, using real-time sensor data and plant feedback to autonomously adjust lighting, temperature, and nutrient dispersal, creating an optimal growth environment. DL-powered image analysis aids in plant health monitoring and disease detection, particularly in large-scale operations. DL algorithms also contribute to crop recommendation systems by analysing historical data on crop performance and environmental parameters, empowering growers to make informed choices. Hydroponics combines ancient wisdom with cutting-edge technology to enhance agriculture's resource efficiency, sustainability, and productivity. From its origins in the Hanging Gardens of Babylon to contemporary innovations in lighting, automation, and data-driven precision, hydroponics plays a pivotal role in the future of agriculture.

Hydroponic systems may minimize ecological footprints, boost yields, and speed up plant development by using carefully calibrated nutrient solutions, artificial lighting, pH, temperature, TDS value, and light intensity monitoring. Plant growth and development in regulated indoor conditions are greatly aided by LED grow lights, thanks to their wide range of spectrums. Hydraulic agriculture may achieve greater production and resource efficiency by combining data analytics, automation, and sustainable lighting systems. Smart control systems that maximize crop production and growth circumstances are made possible by the combination of deep learning and machine learning approaches. Hydroponics, with its historical roots and modern advancements, is still vital to agriculture's future, providing a means of achieving both environmentally friendly production of food and sustainable food.

2. Literature Review

This paper reviews the literature on hydroponic gardening with an emphasis on the use and characterisation of light spectrum. In order to find gaps and potential for more research, it methodically examines earlier work. In order to shed light on the many methods and tactics utilized to investigate the effects of light spectrum on plant development in hydroponic systems, the review synthesizes a variety of research findings. It identifies topics that require more investigation by assessing limits and methodology. The review provides a glimpse into possible directions for further research and development. It provides a framework for creating new methods and techniques for hydroponic gardening, guiding the creation of creative experiments and techniques. The review is essential in guiding future hydroponics research and moving the discipline closer to more effective and sustainable methods.

A novel hydroponic precision agricultural system utilizing fuzzy logic and the Internet of Things is proposed by Surantha et al. (2019). Fuzzy logic controls the distribution of water and nutrients, and the Internet of Things makes it easier to monitor plant nutrition and water requirements. According to experimental data, this approach improves lettuce and bok choy plant development outcomes, leading to bigger leaves. Fuzzy logic and IoT together provide a workable solution for optimizing plant growth in hydroponic systems.

In their exploration of LED grow lights' application in hydroponic growing, Prasetia et al. (2021) emphasize its significance. Real-time clock modules, relays, temperature and humidity sensors, and automated light feeding are all used by the systems. The findings demonstrate that in IoT-based bok choy hydroponics, LED lights are superior to sunshine in terms of increasing fresh weight, leaf count, and plant height. The study sheds information on how well LED lighting solutions work in hydroponic plant development, particularly in automated environments.

Using four machine learning models—support vector regressor (SVR), extreme gradient boosting (XGB), random forest (RF), and deep neural network (DNN)—Mokhtar et al., (2022) investigated the prediction of lettuce yield. Three hydroponic systems were used to cultivate the lettuce, and three different situations were assessed. The root mean square error (RMSE) of 8.88 g was the lowest for the XGB model, and 9.55 g was the lowest for SVR. The greatest RMSE of 12.89 g was generated by the RF model. Scatter Index values less than 0.1 were deemed outstanding in all circumstances. SVR with scenario 3 and DNN with scenario 2 were the two top-performing models, however DNN with scenario 2 was the model that performed best overall.

Ullah, A., et al. (2019) created the suggested technique for tracking and adjusting hydroponic system parameters. It makes use of an Internet of Things architecture with an ESP32 micro-controller to control temperature, humidity, pH, and water level, among other variables. An SMS warning is delivered to the farmer in the event that the reservoir's water level falls below a certain threshold. The farmer may then use a mobile application to remotely refill the water supply. In addition, a DHT11 humidity sensor and an LDR (light dependent resistor) are used to control temperature and light. In addition, a pH sensor is integrated to gauge and track the water solution's acidity or alkalinity in the hydroponic system.

In a study conducted by Liyanage (2023), an automated indoor hydroponic plant growing chamber and contrasted it with a manual setup. The sensor-based system monitored temperature, humidity, pH, and TDS using Arduino-controlled solenoid valves. Similar to the outside system, the automated system kept the temperature, humidity, pH, and EC levels constant. When compared to the manual technique, the automated system greatly improved the development of the tomato and lettuce plants. Higher plant heights and leaf lengths were also displayed by the system. According to the study, by maximizing plant development, raising yields, and promoting well-informed decision-making in hydroponic farming, automated hydroponic systems can better suit plant preferences and agricultural techniques.

Huda et al., (2023) developed a hydroponic system for lettuce using the Nutrient Film Technique (NFT) method. The system circulates nutrient-rich water, preventing root rot and improving nutrient delivery. The system uses a pH sensor and a DHT11 sensor to measure pH levels and temperature. The study found that lettuce plants grew fastest without light, with the largest width found under yellow light. Interestingly, plants under red and yellow lighting displayed the same leaf count. This study offers insights into lettuce plant growth dynamics and NFT hydroponic systems' effectiveness.

Kularbphettong K., et al., (2019) developed an automated system for hydroponic plant development, controlling critical environmental elements like temperature, humidity, and water. The system tracks solution usage and mixes nutritional solutions to achieve required concentrations, allowing for cost estimation and profitability calculations. The study demonstrated successful hydroculture for plant growth, highlighting the system's effectiveness and improved pH sensor stability. The study advances hydroponic farming science and provides advice on optimal plant cultivation.

In a study, Talib et al., investigated how LEDs—which emit red, blue, and white light—affected the growth and development of lettuce. A hydroponic system with multiple tiers that was vertically oriented and exposed to various LED colors was utilized by them. It was found that, in comparison to white LED illumination, red LED lighting produced more leaves—both in terms of number and length—and heavier lettuce. The difference was 28%. Legumes grew 13% faster and had higher chlorophyll content under white LED lighting. According to the study, growing lettuce in a vertical multi-tier hydroponic system benefit greatly from LED lighting.

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Abdullah A. et al.'s research from 2019 makes use of a TDS sensor to measure nutritional solution concentration, a DHT11 temperature sensor to measure nutrient solution temperature, and a PH sensor to detect nutrient solution acidity. Each and every input and output is processed by the Atmega328 microcontroller. The system has an internet connection, which enables remote monitoring and the viewing of sensor information on Android phones. Test findings demonstrate the successful integration and operation of mobile phones and internet networks for temperature and acidity conditions monitoring in hydroponic plants.

According to Sadek, N., et al. (2019), the current study assesses the technical and environmental effects of the smart system that was built on the production of high-value Batavia lettuce. The study shows that, independent of soil fertility, increasing water and energy usage efficiency (saving them by around 80%), tripling productivity per area, and shortening the time yield to reach 45 days compared to 75 days with traditional agriculture are all achievable. In agriculture, it also saves labor and uses less pesticides and fertilizers. During the cultivation time, both with and without the built smart system, the results of Total Dissolved Solids (TDS), Relative Humidity (RH), and Temperature (T) were investigated and assessed.

The research, put out by Lakshmanan, R., et al. (2020), describes the planning and execution of an Internet of Things-based automated smart hydroponics system to meet the demand for food on a worldwide scale and the requirement for sustainable agricultural practices. The data processing and monitoring components of the system include NodeMcu, Node Red, MQTT, and sensors. To control the supply chain, a bot was introduced after a prototype was built, coded, and tested. AI and data science may be used in future research to enhance agricultural results.

The approach that Koge, P., et al. (2020) have suggested satisfies the aforementioned characteristics and is centered around organic plant growth. It is appropriate for a variety of settings, including rooms, terraces, and balconies, and it provides controlled environment capabilities. When well monitored and regulated, it also makes it possible to cultivate a great number of plants in a small area, making it a very productive kind of agriculture. All elements required for plant development are controlled internally using IoT technology. This invention makes it possible for residents of crowded metropolitan areas without access to gardens to produce their own fresh veggies. Furthermore, it meets the requirements of both commercial and home growers.

A hydroponic system was created by Dudwadkar et al. (2020) to boost plant and vegetable development in a regulated setting. Actuators are used by the system to monitor and regulate parameters, which minimizes labor-intensive tasks and guarantees year-round availability. Vegetables and plants are always available throughout the year thanks to remote monitoring, which also lessens dependency on natural environments. The experiment shows how well-managed hydroponic systems increase growth rates and decrease reliance on human labor in agriculture.

As a conclusion, the literature review emphasizes a variety of cutting-edge techniques and innovations in hydroponic agriculture, highlighting the important effects on plant development, resource economy, and preservation of the environment. The studies provide valuable insights into improving hydroponic systems, including machine learning models for lettuce production prediction and fuzzy logic and IoT integration for precision agriculture. LED grow lights are crucial for hydroponic systems, and sensor technology allows for accurate environmental parameter monitoring. Automation and intelligent systems are revolutionizing hydroponic farming by optimizing yield and reducing labor and resource consumption, offering solutions to sustainability and food shortages.

3. Methodology

3.1 Hardware Components

Figure 1 shows the hydroponic system’s hardware setup. List of hardware used in this setup that captures and gives us the data for processing:
Microcontroller (Arduino): This central unit is responsible for managing the flow of data between the various components.
Power Adapter: It regulates different voltage levels for different sensors.
Camera: It captures images and videos using python OpenCV library.
pH Sensor: It measures the pH level under water and it is read by the microcontroller.

Temperature Sensor: It measures the temperature of the environment and sends data to the microcontroller.
Oxygen Sensor: This identifies the oxygen level in the plant.
LED Driver: The microcontroller manages the LED driver to control the LEDs, adjusting their brightness and colour based on the collected data.

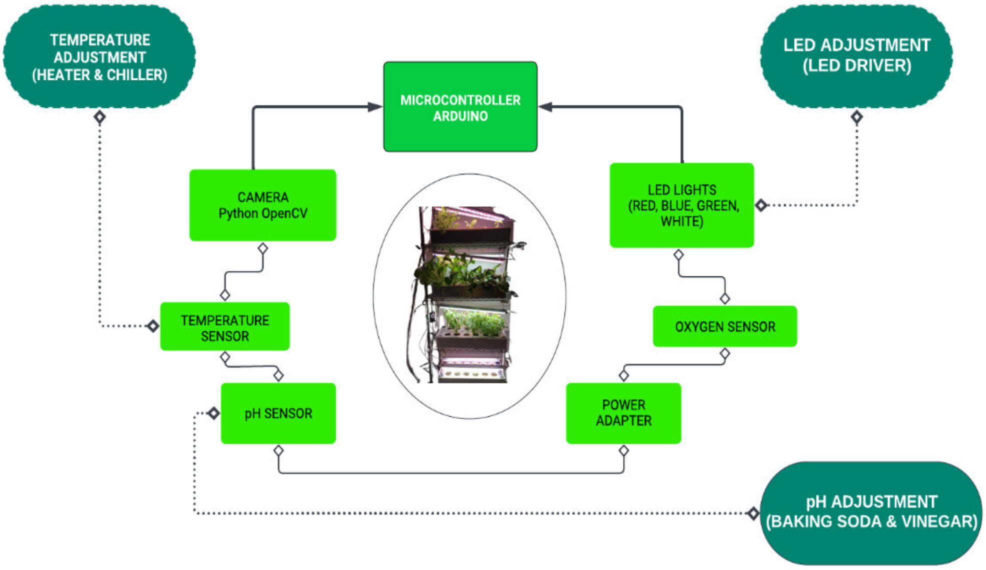

Figure 1: Hardware process setup

3.2 Hardware Work Process

This process involves the continuous monitoring of various sensors and the retrieval of data by a microcontroller, specifically an Arduino Uno. The objective of this operation is to ensure meticulous oversight and control of environmental conditions within a hydroponic system, ultimately optimizing plant growth and health. The microcontroller serves as the central control unit responsible for orchestrating data acquisition from all sensors. It then processes this data, compares it against predefined thresholds, and executes control actions as necessary. These control actions can encompass adjustments to parameters such as pH, temperature, or oxygen levels. . Additionally, the microcontroller has the capacity to log data for subsequent analysis and communicate with external devices or systems for monitoring and control. Arduino Uno contains the python code to read data from various sensors. The camera is initially configured using Python's OpenCV, a versatile open-source computer vision library. Once operational, it consistently captures images or video footage of the hydroponic setup, thereby creating a visual record of the plants' condition. These captured images undergo comprehensive analysis through OpenCV, encompassing crucial tasks such as assessing plant health, monitoring growth progress, and detecting any anomalies or irregularities. . OpenCV employs various image processing techniques to emphasize specific features or colour changes, facilitating the identification of potential plant health issues. Subsequently, the captured images and video footage are wirelessly transmitted through an nRF24L01 module to the Arduino Uno. This module, when connected to the Arduino Uno, enables wireless data transmission not only from essential sensors like the pH sensor, temperature sensor, and oxygen sensor but also from the camera. This wireless capability facilitates remote monitoring, data logging, and the overall control of the hydroponic environment. The camera operates in a continuous loop, adaptinits actions based on the environmental conditions. The pH sensor continually measures the pH level of the nutrient solution within the hydroponic system, producing a digital signal proportional to the pH value. The microcontroller reads this digital signal from the pH sensor. pH is a metric indicating the acidity or basicity of water, with a scale ranging from 0 to 14, where 7 represents neutrality. Values below 7 signify acidity, while values above 7 indicate alkalinity. pH essentially measures the relative concentrations of free hydrogen and hydroxyl ions in the water. Adjustments to pH levels are achieved by adding baking soda to increase pH above 7 or vinegar to decrease it below 7. The temperature sensor is responsible for monitoring and regulating the temperature of the growing environment. Real-time temperature data is provided to the microcontroller by the thermometer, enabling it to maintain optimal conditions specific to the plant species being cultivated. Temperature adjustments are facilitated through the use of heaters and chillers. All temperature readings are wirelessly transmitted to the microcontroller. The oxygen sensor obtains oxygen level data from the plants and transmits it to the Arduino. In this context, oxygen levels remain relatively constant, with no active adjustments or variations. Power adapters are connected to the microcontroller and other electronic components, including the LED driver and sensors, to ensure a stable and uninterrupted power supply. This guarantees the continuous operation of the entire system, allowing the microcontroller to effectively control the various sensors and actuators, such as the camera, pH sensor, thermometer, oxygen sensor, and LED lights. There are four distinct lights (RED, BLUE, GREEN, WHITE) that provide the requisite light spectrum for photosynthesis, enabling plants to thrive in controlled indoor environments. In this experiment, LED lights, under the control of the microcontroller, simulate natural sunlight, ensuring that plants receive the appropriate type and amount of light at various growth stages. The LED driver plays a pivotal role in creating an ideal lighting environment for hydroponic plants by regulating the electrical current and voltage supplied to the LEDs, ensuring their efficient operation and emission of the desired light spectrum. These hardware components collectively govern the entire operational process, with all sensors transmitting data wirelessly via the nRF24L01 module to the Arduino Uno microcontroller.

3.3 Logging Arduino Uno Sensor Data to a CSV File

Logging data from an Arduino Uno to a CSV (Comma-Separated Values) file is a fundamental process, spanning environmental monitoring to industrial automation. Arduino Uno is connected to the desired sensors like pH sensors, temperature sensors, oxygen sensors and camera. A critical part of this initial setup is crafting an Arduino sketch, which is essentially a program instructing the Arduino to read data from these sensors and format it suitably for later transmission. Once the physical connections and sketch are in place, serial communication is established between the Arduino and the computer. This is done using the Serial.begin() function, also specify the baud rate to determine the communication speed. Subsequently, within the Arduino sketch, the Serial.print() or Serial.println() functions come into play to transmit the collected data to the computer via the USB connection.

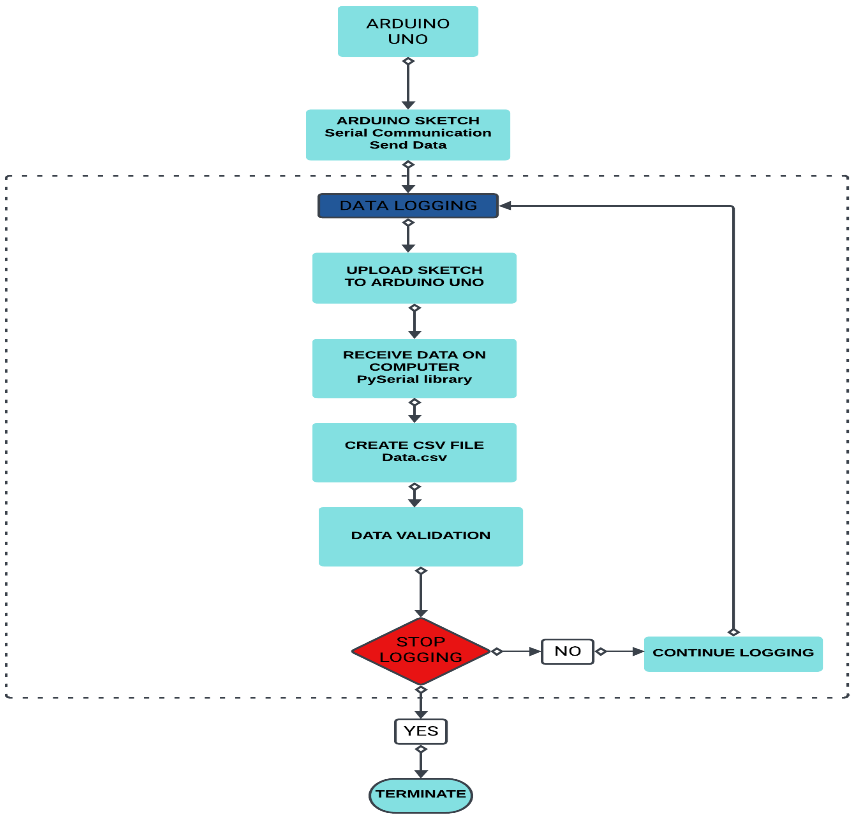

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Figure 2: Arduino to CSV

Proper formatting of data is essential, involving the use of commas to delineate values, ensuring compatibility with the CSV format. For testing and monitoring the data transmission, this can leverage the Arduino IDE's Serial Monitor. It allows real-time observation of data sent from the Arduino Uno, ensuring it aligns with the desired format. On the computer side, data logging necessitates a program or script to accept the data from the Arduino Uno and store it systematically in a CSV file. Python is a favoured choice for this task due to its simplicity and libraries like PySerial, which facilitate communication with the Arduino. Once the script is in place, it's crucial to confirm that the data is accurately formatted and contains any necessary headers in the CSV file to define the data columns. Running the Python script initiates data collection from the Arduino Uno, and the script continues to run until manually terminated. When you wish to conclude data logging, simply press Ctrl+C in the terminal where the Python script is active and choose ‘yes’ to terminate, ‘no’ to continue with data logging. The final output is a CSV file, often named something like 'data.csv,' containing the data from Arduino Uno. This file can be readily accessed and analysed using various data analysis tools, including Microsoft Excel, Google Sheets, or Python's data manipulation libraries such as Pandas. In essence, this process of logging data from an Arduino Uno to a CSV file is a foundational step in data-driven process, enabling efficient data collection and subsequent analysis across a broad spectrum of applications.

Table 1: Parameters extracted from arduino

Temperature (C)	pH Level	Leaf Count	Leaf Height (cm)	Oxygen Level (ppm)	LED Colour	LED Quality (wpsf)
14.2	**6.0**	**2**	**9.8**	**610**	**Blue**	**28**
15.5	**5.8**	**3**	**10.5**	**720**	**Red**	**27**
23.0	**6.5**	**4**	**23.0**	**830**	**Blue**	**40**
16.8	**6.2**	**1**	**8.7**	**750**	**Blue**	**29**

First column of Table 1 represents the temperature in degrees Celsius. Maintaining the right temperature is crucial for lettuce growth. pH level of nutrient solution is sensed by pH sensor ,which is mostly acidic in nature. Leaf Count and Leaf Height is captured by the camera with help of Python OpenCV library Oxygen level column represents the dissolved oxygen level in the nutrient solution, measured in parts per million (ppm). Maintaining adequate oxygen levels is crucial for healthy root development and overall plant growth. Next column represents the colour of the LED grow lights used for providing artificial lighting to the plants. Light Quality column represents the power of the LED grow lights in watts per square foot. Adequate lighting is essential for photosynthesis and plant growth.

3.4 Data Analysis using Machine Learning

The data analysis process is a systematic and iterative approach to extracting valuable insights and knowledge from raw data. The first step is data collection, where relevant data is gathered from various sources or sensors. Collected data is stored in any labelled format like (excel, csv). Table 1 contains set of sample data for process. Here, the dependent variable is “LED Quality“ and the independent variables are “Temperature”, “pH Level”, “Leaf Count” , “Leaf Height ”, “Oxygen Level” and “LED Colour”. Independent variables refers to the

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features of the dataset that includes input variables or attributes that are used to make prediction or classifications and to train the machine learning model. Dependent variable referred as target variable which is the outcome that the model aims to predict or classify and it would be the data which is based on independent variables. In python, drop() is used to split the independent variable and dependent variable or drops the dependent variable. However, raw data is often far from pristine. It may contain errors, missing values, or inconsistencies. Data Preprocessing step involves handling missing data, removing duplicates, standardizing formats, dealing with outliers, and normalizing or scaling numerical features. To identify missing values in the dataset , python uses 'isnull()' and to fill the missing values with mean or median or mode use 'fillna()'. duplicated() identifies duplicate rows. LabelEncoder() is used to encode ordinal categorical variables as integers . Table 1 has one column("LED Colour") which contains categorical values that need to be encoded and convert as integers. Following data preprocessing, exploratory data analysis (EDA) is conducted. EDA helps analysts gain an initial understanding of the data's characteristics by using visualizations like histograms, scatter plots, and summary statistics. This step allows for the identification of patterns, trends, and potential outliers, which can inform subsequent analyses. describe() function generates summary statistics like count, mean, standard deviation, minimum value, maximum value, percentiles. Feature engineering and data transformation come next, where new features are created or existing ones are modified to extract meaningful information. Feature engineering plays a pivotal role in improving the performance of machine learning models, and techniques include creating dummy variables for categorical data, scaling features, creating

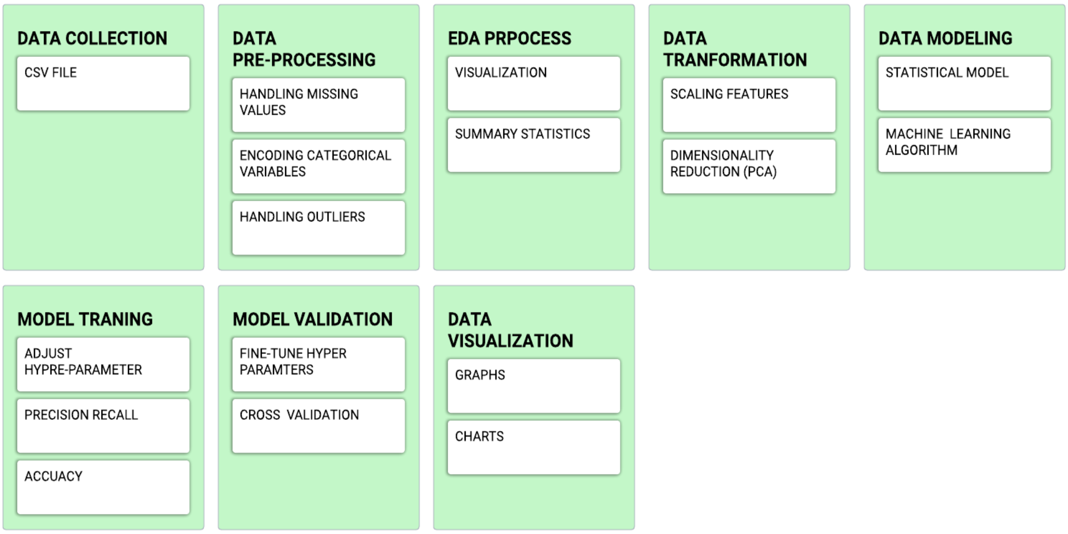

Figure 3: Model Deployment

interaction terms, and dimensionality reduction using methods like Principal Component Analysis (PCA). PCA is used in fields such as data analysis, image processing, and machine learning to simplify complex datasets and extract meaningful information while reducing computational complexity. Once the data is prepared, the modeling phase begins. Depending on the analysis objectives, analysts modelling techniques are selected, such as statistical models (e.g., linear regression) or machine learning algorithms (e.g., decision trees, neural networks). Since the data.csv file contains labelled data with continuous values, LinearRegression() is one of the best and efficiently used algorithm to analyse labelled data. While using Linear regression, "LED Quality" column would be the dependent variable because it holds continuous values. On the other side, "LED Colour" column also need to be analysed. In this case ,to predict "LED Colour" column it must be replaced as dependent variable. This column holds set of categorical values, it should be encoded and convert into discrete set of values. Since it is discrete values, classification algorithm(LogisticRegression) is used to process the analysis. Here, the data is typically split into training and testing sets for model evaluation and validation. The splitting of sets is done using train_test_split() function. This function has a parameter called 'test_size' that helps to evaluate the size of testing set. The testing size should not be greater than training set(i.e test_size=0.2[Here, the test size would be 20% of the dataset]). The model is then trained using the training

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dataset, and hyperparameters are adjusted to optimize its performance. LinearRegression().fit() and LogisticRegression().fit() are used to fit the required model.
Linear Regression Equation:

$$\mathbf{Y = 0+1X} \tag{1}$$

Where:

y - is the target variable,
0 - is the intercept (weight predicted by the model),
1 - is the regression coefficient or slope,
X - is the regressor that helps in predicting the target.

Logistic Regression Equation:

$$\mathbf{P(Y=1|X)=1+e-(\beta0+\beta1X1+\beta2X2+\ldots+\beta nXn)1} \tag{2}$$

Where:

$X1,X2,\ldots,Xn$ are the input features.
$\beta0,\beta1,\beta2,\ldots,\beta n$ are the corresponding coefficients for each feature.

Model evaluation involves assessing its performance using relevant metrics like R-squared (R^2). R-squared (R^2) in machine learning quantifies how well a regression model fits the data, with values closer to 1 indicating a better fit, and it helps assess the proportion of variance explained by the model and this metrics is for linear regression. Accuracy() measures the overall correctness of predictions in logistic regression. Create visualizations to present insights and results. Visualize the predicted "LED Quality (Watts)" and "LED Colours" against the actual values. Use scatter plots, regression plots, or residual plots with the help of matplotlib to assess the model's performance. Seaborn library provides advanced and modern charts and graphs like heatmaps to make the visualization understandable with high accuracy.

4. Results And Discussion

In this study, we embarked on an exploration of hydroponic cultivation, a method revered for its precision and sustainability. Our focus centred on the impact of four distinct LED light colours – red, blue, green, and white – on critical growth factors: temperature, pH levels, light intensity, plant height, leaf weight, leaf count, stem growth, and light quality. Rigorous control measures were implemented to ensure uniformity, with LEDs calibrated for consistent intensity and photoperiods. Continuous monitoring of temperature and pH levels in the nutrient solution complemented our precision. Initial findings shed light on the diverse effects of LED colours on hydroponic plant growth. Red light emerged as a catalyst for vertical growth, while blue light was found to enhance leaf weight and compactness. Green light appeared to potentially modulate pH levels, and white light, with its broad spectrum, harmonized various growth parameters. The recommended or average range of temperature, which is continuously monitored by the temperature sensor, is between 13°C to 25°C, and the best temperature would be 19°C. The optimal pH level for growing lettuce in a hydroponic system is typically in the range of 5 to 6.8, and the best pH level is 6.2. The average lettuce leaf count is 1 to 3, rarely being 4. The optimal leaf height of lettuce ranges between 9 to 14 cm, and the best is 15cm. The average oxygen levels produced within the recommended range of 500 to 860 ppm, and the best one is 750. "Blue" and "Red" LED colors are commonly used for different stages of plant growth. "Blue" LED would be the best for Lettuce in Hydroponic. LED quality ranging from 26 to 45 watts per square foot, and the best would be 29wpsf. Beyond just intensity, spectral composition was identified as a critical determinant. As we look to the future, our research endeavors venture into uncharted territories of machine learning and deep learning techniques, including predictive modeling, Convolutional Neural Networks (CNNs), clustering algorithms, and Principal Component Analysis (PCA). These approaches promise deeper insights into the intricate interplay between LED colors and plant growth, offering tailored cultivation strategies for vitality and optimized yield.

5. Conclusion

The present study aimed to address the needs of light energy and save it for future use. The combination of data analysis, machine learning, and hydroponic technology presents a promising avenue for enhancing crop production and resource efficiency. This research lays the foundation for future investigations into the intricate interplay between environmental factors and plant growth, fostering innovation in agriculture. The models provide valuable insights, there are limitations. The dataset is limited to a few LED colours, and more data with a wider range of colours could improve model accuracy. Future work could involve exploring advanced machine learning techniques such as neural networks to capture complex interactions between variables. Incorporating real-time monitoring and control systems using deep learning and IoT devices can further enhance precision in hydroponic cultivation.

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