Precise Lighting Electronic System Applied to Vertical Farming to Maximize Crop Growth Controlled and Monitoring by Free IoT Platforms

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1. Abstract

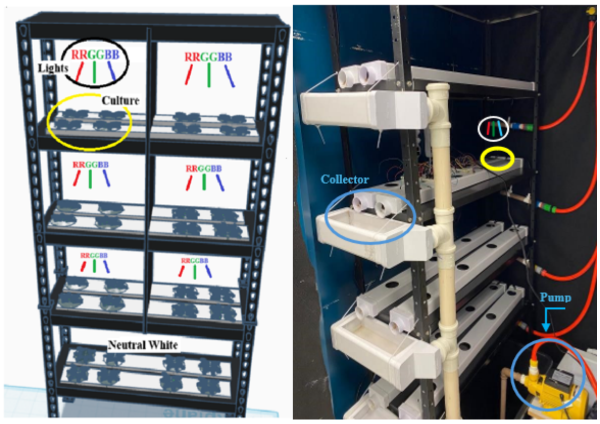
This paper explores concepts related to electronic systems that are part of the vast network of physical devices connected to the Internet. These devices are equipped with nano processors, sensors, and actuators that enable the collection and exchange of data with other electronic equipment in real time, allowing for the automatic monitoring and control of complex systems across various areas of human activity. In this scenario, this work describes the design of a smart electronic illumination system focusing on vertical farms. The results show that the Lighting Electronic System developed can be controlled and monitored by different commercial and free IoT platforms and is able to supply different spectrums of light energy for the crop, aiming to optimize the indoor food production of the vertical farms.

2. Introduction

The rapid evolution of Industry 4.0, driven by advancements in nanoelectronics, integrated circuits (ICs), sensors, actuators, and Artificial Intelligence (AI), has transformed various sectors, such as those related to industrial automation, healthcare, telecommunications, automotive, aerospace, etc. The central point of this transformation is the development of intelligent, efficient, and optimized systems that leverage the Internet of Things (IoT) technologies. The IoT devices, utilizing nanocontrollers, sensors, and actuators, collect and transmit data to the cloud for intelligent processing, enabling precise decision-making and automation for increased productivity, security, energy efficiency, etc. [1-2]. In this context, this research aims to implement an IoT-based electronic system to provide different spectrums of light energy for the crops of a vertical farm. The lighting electronic system was built with the ESP32 microcontroller, a versatile hardware platform with built-in Wi-Fi, Bluetooth, and multiple interfaces, including General Purpose Input/Output (GPIO), Serial Peripheral Interface (SPI), Inter-Integrated Circuit (I2C), and Analog-to-Digital Converter (ADC), enabling efficient sensor and actuator integration. Thus, the main objective is to design an intelligent RGB (Red, Green, Blue) lighting system focusing on vertical farms. The electronic system is able to provide different spectrums of light energy to optimize crop growth, enhance the Photosynthetic Photon Flux Density (PPFD), and simultaneously improve energy efficiency, sustainability, and cost reduction for efficient agriculture in smart farming environments [3-4].

3. Methodology

First, a study of the vertical farming structure was conducted, as shown in Figure 1, which displays the 3D representation (Figure 1.a) of the structure to facilitate the understanding of the physical prototype (Figure 1.b).



(a) (b)

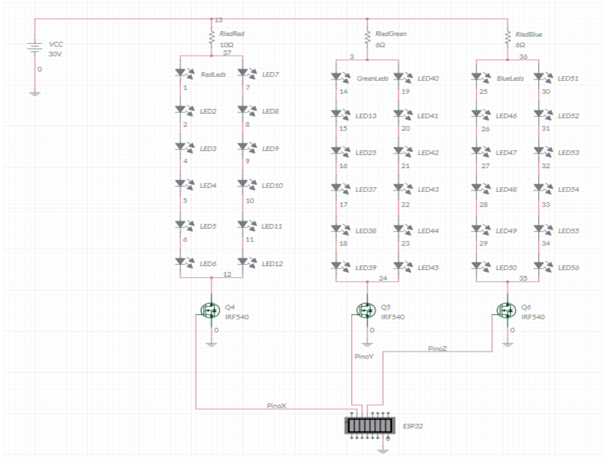
Fig.1. *Physical structure of the vertical farm prototype (b), along with its 3D representation (a), located in the IoT Laboratory at the FEI University Center (FEI).*

This research project aimed to design an automatic RGB lighting system with PWM control for food production. The following calculations were performed to define the power supply and components of the system, considering the specifications of the high-luminosity red, green, and blue LEDs, as indicated in Table 1.

Table I. *LEDs Datasheet used in this work.*

Product N.^{O}	Forward Voltage	Forward Current	Lumen (lm)
3W Red	2.4-2.6V	700mA	60-70 l
3W Blue	3.2-2.6V	700mA	30-40 l
3W Green	3.2-2.6V	700mA	140-160

Based on the LED datasheet, the required voltage supply is determined to power two parallel sets of 6 series-connected red, green, and blue LEDs, totaling 36 LEDs. This is shown in Figure 2, which illustrates the electrical circuit (schematic) of the RGB LED lighting system controlled by Pulse Wide Modulation (PWM) technic. The system is powered by a single power supply



that will serve only one floor partition.

Fig.2. *Electronic Circuit of the RGB LED Lighting System Controlled by PWM.*

The programming framework, including the Message Queuing Telemetry Transport (MQTT) communication, was implemented on the ESP32. The device connects to the Wi-Fi network using the provided credentials and is set up by an MQTT client, with the broker address and a unique identifier. The RGB LED rows are controlled via PWM pins (General Purpose Input Output, GPIOs) of the ESP32, with each row mapped to specific MQTT topics for red, green, and blue LEDs on the left and right sides, totaling 6 PWM pins per floor. The PWM frequency is set to 5000 Hz for smooth transitions. The PWM values' range is defined from 0 (off) to 1023 (max intensity) with 10-bit resolution, and LED intensity is adjusted via MQTT messages. Upon receiving a message, the ESP32 updates the LED intensity, stores the value locally, and publishes a response. During initialization, stored values are synchronized with the broker. The MQTT client connects, subscribes to topics, and processes incoming messages continuously, safely disconnecting if interrupted.

Finally, the electronic circuit of the RGB LED lighting system developed by this research project is in operation and it is illustrated in Figure 3.

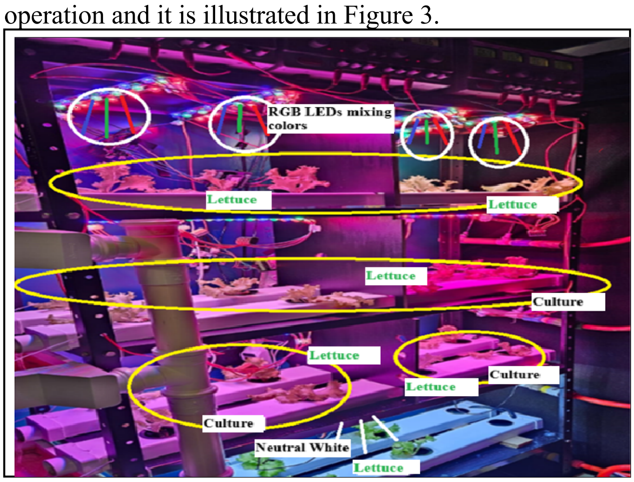


Fig.3. *Electronic circuit of the RGB LED lighting system in operation at IoT Laboratory of FEI University Center.*

4. Results

Implementing the RGB LED lighting system for the vertical farm prototype met the desired specifications. Tests with varying light intensities for each RGB LED successfully achieved all color combinations. Voltage and current measurements showed a maximum error of less than 10%, with the maximum current at 688 mA (close to the LED datasheet value of 700 mA) and the voltage within the 30 V limit. The genetic algorithm-based circuit efficiently adapted the lighting system for lettuce cultivation and can be adjusted for other crops by modifying parameters like light spectrum, intensity, and exposure time. The system generated a PPFD of 200 µmol/m²/s, meeting lettuce cultivation needs. Future improvements could expand the system for crops like arugula, spinach, and other short-cycle vegetables.

5. Conclusions

The development of the intelligent RGB lighting system for vertical farms in controlled environments has made significant advancements in cultivation automation, particularly in lighting control. However, energy consumption remains relatively high due to the power used by the LEDs.

The results show that, while the system allows for more precise and efficient lighting control, there are opportunities to optimize energy consumption. Future improvements could explore additional technologies or energy-efficient strategies to reduce LED power usage. Therefore, this project has advanced automation in controlled cultivation and paved the way for new lighting management methods in vertical farming. Refining the system and addressing energy consumption can further enhance planting production and quality.

Acknowledgments

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