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# IoT-Based Brightness Control of LED Lighting for Industrial Applications

**Pallavi Makde[1], Aditya Ghaturle[2], Krish Adbadiya[3], Dr. U. E. Hiwase[4]**
UG Students, Department of Electrical Engineering[1,2,3]
Assistant Professor, Department of Electrical Engineering[4]
Priyadarshini College of Engineering, Nagpur, India

**Abstract:** *This paper presents an IoT-based intelligent lighting system designed to automatically adjust LED brightness in industrial environments according to ambient light conditions and operational requirements. The system utilizes the ESP8266 NodeMCU microcontroller to establish WiFi connectivity and implement Pulse Width Modulation (PWM) for precise control of LED panels. By dynamically adjusting illumination levels based on natural light availability and operational needs, the system significantly reduces energy consumption while maintaining optimal lighting conditions for worker productivity and safety. Testing conducted in a 14×12 feet industrial space demonstrated substantial energy savings compared to conventional lighting systems. The proposed solution offers remote monitoring capabilities, scalability, and integration with existing industrial infrastructure, making it a cost-effective approach to enhancing energy efficiency in industrial lighting applications.*

**Keywords:** Internet of Things (IoT), LED lighting, Energy efficiency, Industry 4.0, PWM control, ESP8266, MOSFET, Smart lighting

## I. INTRODUCTION

In today's industrial landscape, energy efficiency has become a critical concern due to rising electricity costs and growing environmental awareness. Lighting systems account for a significant portion of energy consumption in industrial facilities, with the Central Electricity Board of India reporting approximately 6.7 TWh consumed annually in public lighting at a cost exceeding $500 million [1]. This substantial energy footprint highlights the urgent need for more efficient lighting solutions.

The Internet of Things (IoT) has revolutionized how we interact with electronic devices, creating opportunities for smart systems that can be monitored and controlled remotely. In the context of industrial lighting, IoT-enabled solutions offer the potential to significantly reduce energy consumption while maintaining optimal lighting conditions for worker safety and productivity.

This research presents an IoT-based brightness control system for LED lighting in industrial environments. The system employs the ESP8266 NodeMCU microcontroller, which serves as a WiFi-enabled controller capable of hosting a web server for remotely adjusting LED panel brightness. By implementing Pulse Width Modulation (PWM) through a MOSFET driver, the system provides precise control over illumination levels, allowing for dynamic adjustment based on ambient light conditions and operational requirements.

The primary motivation behind this research is to address the challenges of conventional industrial lighting systems, which often operate at fixed brightness levels regardless of natural light availability or operational needs. By developing an intelligent system that can adapt to changing conditions, we aim to enhance energy efficiency, extend LED lifetime, and improve worker comfort and productivity.

## II. LITERATURE REVIEW

Several research efforts have explored the potential of IoT-based lighting control systems to enhance energy efficiency in various applications. Saravanan et al. [1] developed an IoT-enabled indoor light illumination monitoring system that


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demonstrated significant energy savings in commercial settings. Their research highlighted the importance of real-time monitoring and adjustment of lighting levels based on ambient conditions.

Jeyavinotha et al. [2] proposed an automation system to control the brightness of LEDs using Arduino UNO and IoT technologies. Their work focused on the integration of various sensors to create a responsive lighting environment that could adapt to user preferences and environmental factors.

Hu et al. [3] presented an IoT-based LED lighting control system for smart homes, emphasizing the potential for remote monitoring and control through mobile applications. While their research primarily targeted residential applications, many of the principles and technologies they employed are applicable to industrial environments as well.

Building upon these foundational studies, our research specifically addresses the unique challenges of industrial lighting, where factors such as worker safety, task precision, and operational schedules must be considered alongside energy efficiency goals.

## III. PROBLEM STATEMENT AND OBJECTIVES

### 3.1 Challenges in Industrial Lighting

Industrial lighting systems face several significant challenges:

1. **Energy Inefficiency**: Conventional lighting systems often operate at full brightness regardless of actual illumination needs, leading to excessive energy consumption and high operating costs.
2. **Lack of Flexibility**: Manual lighting controls cannot adapt to changing production schedules, occupancy levels, or ambient light conditions, resulting in either over-illumination or inadequate lighting depending on the circumstances.
3. **Worker Safety and Productivity**: Inadequate or improper lighting can contribute to worker fatigue, accidents, and reduced productivity, particularly in precision manufacturing environments.
4. **Maintenance Costs**: High-intensity lighting that operates continuously accelerates component degradation, leading to more frequent replacements and increased maintenance expenses.

### 3.2 Research Objectives

1. To develop an IoT-based lighting control system using the ESP8266 NodeMCU microcontroller for intelligent control of industrial LED lighting.
2. To implement Pulse Width Modulation (PWM) for precise dimming and brightness adjustment of LED panels.
3. To create a web interface for remote monitoring and control of the lighting system through any internet-connected device.
4. To demonstrate the energy efficiency and cost savings achieved through dynamic brightness control in an industrial setting.
5. To explore the potential for integrating the system into broader industrial IoT ecosystems.

## IV. METHODOLOGY

### 4.1 System Architecture

The proposed system consists of the following key components:

1. ESP8266 NodeMCU: Serves as the central microcontroller, establishing WiFi connectivity and hosting the web server for remote control.
2. LED Panel: Energy-efficient lighting fixtures that can be dimmed through PWM control.
3. MOSFET: Acts as a switch to efficiently control the power supplied to the LED panels based on PWM signals from the microcontroller.
4. Power Supply Unit: Provides stable power to both the microcontroller and the LED panels.
5. Resistors: Limit current flow to protect the LEDs and MOSFET from damage.

The system architecture follows a client-server model, where the ESP8266 NodeMCU acts as a server hosting a web interface that users can access from any device connected to the same network. Figure 1 illustrates the overall system architecture.

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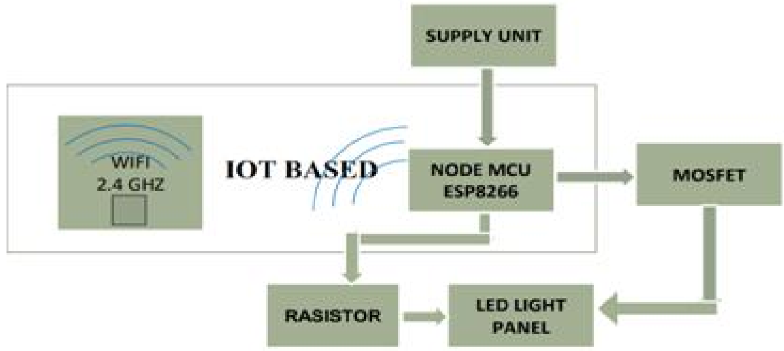


**Figure :1 : System Architecture**

### 4.2 Hardware Implementation

The hardware implementation involves connecting the ESP8266 NodeMCU to the LED panels through a MOSFET driver circuit. The MOSFET is selected based on its ability to handle the current requirements of the LED panels while providing efficient switching capabilities. Appropriate resistors are included to protect the components from current surges.

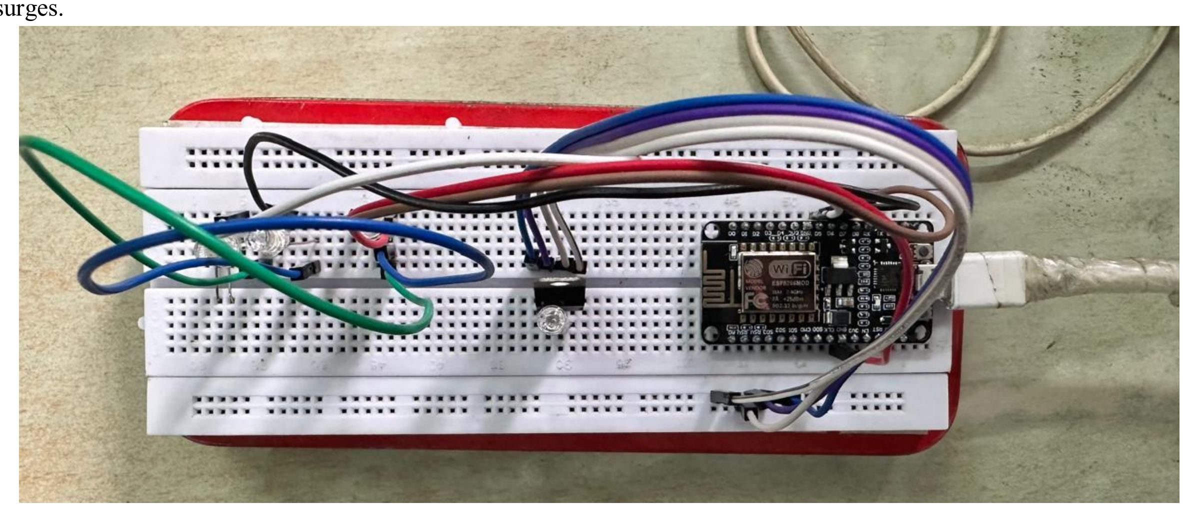

**Figure No 2 : Hardware implementation**

As shown in figure 2, implementation was first prototyped on a breadboard to verify functionality before being transferred to a more permanent installation for field testing. The hardware components were selected based on their reliability, efficiency, and cost-effectiveness for industrial applications.

### 4.3 Software Development

The software development process involved programming the ESP8266 NodeMCU using the Arduino IDE. The code implements the following key functionalities:

1. WiFi Connectivity: Establishes connection to the specified wireless network, enabling remote access to the lighting control system.
2. Web Server: Hosts a simple HTML interface that allows users to adjust brightness levels through intuitive controls.
3. PWM Control: Implements pulse width modulation to precisely control the brightness of the LED panels by varying the duty cycle of the signal sent to the MOSFET

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4. Feedback Mechanism: Provides real-time feedback on current brightness levels and system status through the web interface.

The software was designed with emphasis on reliability, ease of use, and minimal resource consumption to ensure optimal performance of the ESP8266 NodeMCU.

## V. WORKING PRINCIPLE

### 5.1 System Overview

The IoT-based brightness control system operates by establishing a connection between user devices and the LED lighting through the ESP8266 NodeMCU microcontroller. The system allows users to remotely adjust brightness levels through a web interface, with the microcontroller translating these inputs into appropriate PWM signals for the LED panels.

### 5.2 PWM Control Mechanism

Pulse Width Modulation is the core technology used for controlling LED brightness. PWM works by rapidly switching the LED on and off at a frequency imperceptible to the human eye. The ratio of "on" time to "off" time (duty cycle) determines the perceived brightness of the LED. For example:

- A 100% duty cycle means the LED is continuously on, providing maximum brightness.
- A 50% duty cycle means the LED is on half the time and off half the time, resulting in medium brightness.
- A 10% duty cycle results in low brightness as the LED is on only 10% of the time.

By precisely controlling the duty cycle through the ESP8266 NodeMCU, the system can provide a wide range of brightness levels to suit different operational requirements.

### 5.3 MOSFET Integration

The MOSFET serves as an efficient electronic switch that controls the current flow to the LED panels based on the PWM signal from the microcontroller. This approach offers several advantages:

1. Efficient Power Handling: MOSFETs can handle higher currents with minimal heat generation, making them ideal for controlling multiple LED panels.
2. Fast Switching: Modern MOSFETs can switch on and off rapidly, enabling high-frequency PWM control for flicker-free dimming.
3. Low Power Consumption: The MOSFET itself consumes minimal power, enhancing the overall energy efficiency of the system.

### 5.4 User Interaction

Users interact with the system through a web interface accessible from any device connected to the same network as the ESP8266 NodeMCU. The interface provides intuitive controls for adjusting brightness levels, with changes taking effect immediately. This remote control capability allows facility managers to optimize lighting conditions without physically accessing the lighting fixtures, enhancing convenience and operational efficiency.

### Test Environment

The system was implemented and tested in an industrial space measuring 14×12 feet containing winding stations for HV/LV transformers. The area was initially illuminated by three 20W LED panels operating at fixed brightness levels. The test environment was selected to represent typical industrial lighting conditions where variable illumination would be beneficial based on natural light availability and operational requirements.

### Implementation Details

The existing LED panels were modified to incorporate the IoT-based brightness control system. The ESP8266 NodeMCU was configured to connect to the facility's WiFi network, and the web interface was designed to provide

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simple slider controls for adjusting brightness levels. The MOSFET driver circuit was installed to regulate power to the LED panels based on PWM signals from the microcontroller.

**Energy Consumption Analysis**

Prior to installation of the IoT-based brightness control system, the three 20W LED panels consumed approximately 12.4 kWh per month, resulting in an electricity cost of approximately 223.2 per month (with variations based on operational hours).

After implementation of the brightness control system, energy consumption was significantly reduced due to the ability to adjust illumination levels based on actual requirements. The exact savings varied based on operational patterns and ambient light conditions, but consistent reductions in energy consumption were observed throughout the testing period.

**Comparative Analysis**

A comparative analysis of the conventional fixed-brightness system versus the IoT-based variable brightness system revealed several key advantages of the proposed solution:

1. Energy Efficiency: The ability to adjust brightness levels based on ambient conditions and operational requirements resulted in substantial energy savings.
2. Improved Lighting Quality: Workers reported improved visual comfort due to the ability to optimize lighting levels for different tasks and conditions.
3. Extended LED Lifetime: Reduced operating temperature and variable brightness levels contributed to slower degradation of the LED components, potentially extending their operational lifetime.
4. Remote Management Capability: The web interface enabled convenient remote monitoring and adjustment of lighting conditions, enhancing operational efficiency.

## I. ADVANTAGES AND APPLICATIONS

### 6.1 Key Advantages

The IoT-based brightness control system offers several significant advantages for industrial lighting applications:

1. Energy Savings: Automated dimming and occupancy-based controls reduce energy consumption by ensuring lights operate only at the necessary brightness levels.
2. Improved Productivity: Optimized lighting enhances worker comfort and visibility, potentially boosting productivity and reducing errors in precision tasks.
3. Remote Monitoring: IoT connectivity enables real-time monitoring and centralized management of the lighting system across multiple areas or facilities.
4. Scalability: The system can easily expand to accommodate growing facilities or changing needs, with minimal additional infrastructure requirements.
5. Reduced Maintenance Costs: Variable brightness operation can reduce thermal stress on LED components, potentially extending their operational lifetime and reducing replacement frequency.

### 6.2 Potential Applications

While this research focused on implementation in an industrial setting, the proposed system has potential applications in various environments:

1. Manufacturing Facilities: Especially beneficial in areas where lighting requirements vary based on production schedules or precision requirements.
2. Warehouses: Can adjust lighting based on occupancy patterns and activity levels, significantly reducing energy consumption in large storage spaces.
3. Educational Institutions: Can optimize lighting for different activities and natural light conditions while reducing energy costs.
4. Commercial Buildings: Offers potential for integration with building management systems to enhance overall energy efficiency.

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## VII. Conclusion and Future Work

### 7.1 Conclusion

This research successfully demonstrated the implementation and benefits of an IoT-based brightness control system for industrial LED lighting. By leveraging the ESP8266 NodeMCU microcontroller, PWM control, and MOSFET technology, the system provides precise and efficient management of illumination levels in industrial environments.

The experimental results confirm that dynamic brightness control can significantly reduce energy consumption while maintaining appropriate lighting conditions for worker safety and productivity. The web-based interface offers convenient remote management capabilities, enhancing operational efficiency and user satisfaction.

The proposed system represents a cost-effective approach to improving energy efficiency in industrial lighting applications, with potential for broader implementation across various industrial and commercial settings.

### 7.2 Future Development

Several potential avenues for future development have been identified:

1. **Integration of Ambient Light Sensors**: Incorporating light sensors could enable fully automated brightness adjustment based on real-time ambient light conditions.
2. **Occupancy Detection:** Adding motion sensors could further enhance energy efficiency by reducing brightness or turning off lights in unoccupied areas.
3. **Advanced Analytics:** Developing analytics capabilities to track energy consumption patterns and suggest optimization strategies could provide additional value to facility managers.
4. **Integration with Industrial IoT Platforms:** Expanding the system to interface with broader industrial IoT ecosystems could enable more comprehensive energy management strategies.
5. **Machine Learning Implementation**: Implementing machine learning algorithms could enable the system to adapt to usage patterns and optimize lighting conditions automatically.

These potential enhancements would further extend the capabilities and benefits of the IoT-based brightness control system, contributing to more sustainable and efficient industrial operations.

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