



# Implementation of IoT-Based Smart Lighting for Volleyball Courts Using NodeMCU and Blynk for RGB Control

Anis Nurcahya<sup>1\*</sup>, Enang Rusnandi<sup>2\*</sup>, Raden Deden Ahmad Hidayat<sup>3\*</sup>  
Teknologi Rekayasa Perangkat Lunak <sup>1</sup>, Politeknik Mardira Indonesia <sup>1</sup>, Teknologi Rekayasa Perangkat Lunak <sup>2</sup>, Politeknik Mardira Indonesia  
<sup>2</sup>, Teknologi Rekayasa Perangkat Lunak <sup>3</sup>, Politeknik Mardira Indonesia <sup>3</sup>

*email : anisnurcahya267@gmail.com<sup>1\*</sup>, enang@poltekni.ac.id<sup>2\*</sup>, radenspot@gmail.com<sup>3</sup>*

## ABSTRACT

*Lighting on a volleyball court plays a critical role in ensuring visual comfort and player safety during evening training sessions and matches. However, many existing installations still rely on conventional, manually operated lighting that lacks dynamic control over color and intensity, limiting both user experience and energy efficiency. This study proposes the design and implementation of an Internet of Things (IoT)-based smart lighting system for a volleyball court that incorporates color-control capabilities using RGB LED luminaires. The system is built on a NodeMCU (ESP8266) microcontroller as the main controller, a Wi-Fi network for communication, and the Blynk application as a mobile interface for remote operation. The research follows a system design and development methodology, covering requirements analysis, hardware-software co-design, implementation, and experimental evaluation. Test results demonstrate that the system can reliably control on/off status, brightness levels, and RGB color in real time through the Blynk interface while maintaining stable wireless connectivity. These findings indicate that the proposed IoT-based smart lighting solution simplifies lighting management, enhances the flexibility of illumination, and offers potential gains in energy efficiency, making it a promising approach for modern, efficient, and interactive volleyball court lighting.*

**Keywords:** *Internet of Things; smart lighting; NodeMCU; RGB LED; Blynk*

## ABSTRAK

**Pencahayaan pada lapangan voli memiliki peran penting dalam menjamin kenyamanan visual dan keselamatan pemain selama sesi latihan maupun pertandingan pada malam hari. Namun, banyak instalasi yang masih menggunakan sistem konvensional dengan pengoperasian manual serta belum menyediakan kontrol dinamis terhadap warna dan intensitas cahaya, sehingga membatasi pengalaman pengguna dan efisiensi energi. Penelitian ini mengusulkan perancangan dan implementasi sistem penerangan cerdas berbasis Internet of Things (IoT) pada lapangan voli dengan kemampuan pengaturan warna menggunakan lampu LED RGB. Sistem dibangun dengan mikrokontroler NodeMCU (ESP8266) sebagai pengendali utama, jaringan Wi-Fi sebagai media komunikasi, dan aplikasi Blynk sebagai antarmuka seluler untuk pengendalian jarak jauh. Pendekatan yang digunakan adalah desain dan pengembangan sistem, mencakup analisis kebutuhan, perancangan perangkat keras dan perangkat lunak, implementasi, serta evaluasi eksperimental. Hasil pengujian menunjukkan bahwa sistem mampu mengendalikan status nyala/mati, tingkat kecerahan, dan warna LED RGB secara andal dan real-time melalui antarmuka Blynk dengan konektivitas nirkabel yang stabil. Temuan tersebut mengindikasikan bahwa solusi penerangan cerdas berbasis IoT ini menyederhanakan pengelolaan pencahayaan, meningkatkan fleksibilitas iluminasi, serta berpotensi mendukung penghematan energi, sehingga layak dipertimbangkan sebagai pendekatan modern untuk penerangan lapangan voli yang efisien dan interaktif.**

**Keywords:** **Internet of Things; Pencahayaan Pintar; NodeMCU; RGBLED; Blynk**

## INTRODUCTION

Adequate illumination on volleyball courts plays a direct role in ensuring visual comfort and safety during evening sports activities, yet current practices continue to rely heavily on conventional systems that are manually operated, function in a single mode, and lack flexibility in adjusting light intensity or spectral characteristics. This condition not only complicates facility management when lighting requirements shift—for instance, between training sessions and competitive matches—but also creates opportunities for energy waste, as luminaires tend to operate at fixed brightness levels without demand-responsive adjustments. In line with sustainability studies in sports facilities, the adoption of LED technology and more intelligent control systems is often regarded

as a strategic step toward enhancing energy efficiency while maintaining service quality in illumination (Huang & Xiao, 2023). The integration of Internet of Things (IoT) technologies in lighting systems, commonly referred to as smart lighting, has been widely implemented to improve energy efficiency, ease of management, and flexibility in light modulation (Sirait et al., 2023).

The motivation for this research is to develop an Internet of Things (IoT)-based smart lighting solution that enables facility managers to perform real-time remote control over ON/OFF status, brightness, and color of luminaires, thereby rendering the lighting system more adaptive and manageable. From a theoretical standpoint, this study employs the Design Science Research (DSR) framework, which emphasizes the creation of artifacts relevant to real-world problems and the structured evaluation of their utility through systematic testing (Zolbanin & Aubert, 2025). In terms of implementation, the selection of NodeMCU/ESP8266 is justified by its integrated Wi-Fi connectivity and peripheral features such as pulse-width modulation (PWM) for brightness and color control of LEDs, making it a viable platform for prototyping network-based lighting control systems.

The objective of this research is to design, implement, and evaluate a prototype IoT-based smart lighting system for volleyball courts with a mobile application interface (Blynk), enabling lighting control to be performed rapidly, reliably, and conveniently via mobile devices. The urgency of this study lies in the need to modernize the management of sports facility lighting toward more efficient, responsive systems with the potential to support energy conservation, while simultaneously enriching the empirical evidence base for IoT applications in sports domains—an area that has received relatively less scholarly attention compared to residential or commercial building contexts. Furthermore, given the DSR evaluation approach that demands rigorous justification of artifact performance and utility (Baskerville et al., 2026), this research is expected to provide a foundation for future enhancements, such as sensor-based automation or quantitative energy consumption measurement, thereby strengthening the solution for broader-scale field adoption. Previous studies have demonstrated that IoT-based lighting control systems integrated with applications such as Blynk facilitate direct control through mobile devices (Rizky Ababil et al., 2025).

## METHODOLOGY

This research adopts the Design Science Research (DSR) paradigm in combination with iterative prototyping. The selection of this methodology is grounded in two key considerations: First, DSR constitutes a systematic research paradigm that is particularly effective for developing innovative solutions in the context of embedded systems and IoT (Zolbanin & Aubert, 2025). Second, prototyping enables functional testing and evaluation to be conducted incrementally, allowing the artifact to be optimized according to evolving requirements (Sommerville, 2021).

The research was conducted through five distinct phases. **Phase 1: Problem Identification** focused on delineating practical challenges, including: (1) the limitations of existing lighting systems in volleyball courts, which fail to respond to dynamic operational needs; (2) high energy consumption resulting from the absence of automated control mechanisms; and (3) the lack of flexible color and intensity adjustment features to accommodate diverse types of sports activities.

**Phase 2: Solution Objectives** involved the precise definition of specific objectives for the IoT-based smart lighting system, encompassing: (1) real-time ON/OFF control capability via a mobile application; (2) brightness adjustment within a range of 0–255 with fine granularity; (3) full-spectrum RGB color control for LED luminaires; and (4) system response to user commands with latency not exceeding 2 seconds.

**Phase 3: Design and Development** comprised two principal components. First, the system architecture was designed in a layered structure: (a) a perception layer (sensing/actuating) incorporating RGB LED modules and auxiliary sensors; (b) a processing layer utilizing a NodeMCU microcontroller based on ESP8266 with integrated Wi-Fi connectivity; (c) a communication layer employing Wi-Fi for real-time data transmission between nodes and the cloud; and (d) a presentation layer implemented through the Blynk application, providing an intuitive user interface for remote control. Second, the technical design specifications included NodeMCU ESP8266 as the main microcontroller (80 MHz clock frequency, 160 KB RAM), common-cathode RGB LEDs with 2V forward voltage per channel, a 4-channel relay module for power switching, and a 5V/10A power supply. The Blynk library was integrated for cloud communication, while pulse-width modulation (PWM) library functions enabled LED brightness control. Communication protocols relied on the REST API provided by the Blynk platform to transmit lamp states and control commands.

**Phase 4: Artifact Demonstration** involved a series of functional test scenarios: (1) ON/OFF control testing from off to on states with response time monitoring; (2) brightness adjustment from 0% to 100% in 10% increments; (3) color changes via the Blynk application's color picker with visual verification of LED output; and (4) Wi-Fi connection stress testing through repeated

disconnection and restoration cycles to evaluate system resilience. Demonstration outcomes were documented through response-time data logs and visual observations.

**Phase 5: Evaluation** was conducted using a multi-method approach that combined analytical measurements, field observations, and system performance analysis (Zolbanin & Aubert, 2025). Technical evaluation assessed: (a) response time—the interval from user command issuance to system response (target: <2 seconds); (b) connection stability—the percentage of time the Wi-Fi connection remained active without interruption during sustained operation; (c) color accuracy—the precision of displayed RGB colors relative to input values (target:  $\pm 5\%$ ); and (d) brightness resolution—the system's ability to render 256 distinct brightness levels without visual artifacts. Functional evaluation verified that: (a) all ON/OFF commands were executed successfully (100% success rate); (b) brightness adjustments were responsive and smooth without flickering; (c) LED colors matched user selections; and (d) no errors or application crashes occurred during the testing period.

Data were collected through two principal techniques. System logging involved automatic recording of technical data by the NodeMCU, including command timestamps, response times, connection status, and sensor values. Structured observation entailed functional testing against predefined checklists to ensure evaluation consistency, with each function's status documented as "successful," "failed," or "successful with notes," accompanied by problem descriptions where applicable.

The artifact was deemed successful if it satisfied four criteria: (1) Functional Success—all primary features (ON/OFF, brightness control, color control) operated according to specifications with a 100% success rate across repeated tests; (2) Performance Success—average response time below 1.5 seconds and connection stability exceeding 98% during sustained operation; (3) Design Success—architecture and implementation adhered to best practices in embedded systems and IoT development as reflected in current literature; and (4) Contribution Success—the artifact and research methodology contributed novel knowledge to the domain of smart lighting systems for sports facilities, particularly regarding technology integration and practical implementation.

## RESULT AND DISCUSSION

The research identified practical needs in volleyball court lighting, which currently remains dependent on manual operation, lacks adaptivity to varying activity types, and provides no flexibility in brightness or color adjustment—factors that potentially compromise visual comfort and facility management efficiency. Problem formulation was conducted by delineating primary functional requirements—remote ON/OFF control, brightness adjustment, and RGB color control—alongside non-functional requirements such as rapid response and stable connectivity, thereby ensuring that the proposed solution adequately captures the complexity of the operational context.

```
66 <body>
67 <div class="container">
68 <h2> Smart RGB Lighting</h2>
69
70 <!-- POWER -->
71 <div class="power">
72 <button id="power">D</button>
73 </div>
74
75 <!-- PREVIEW -->
76 <div class="preview" id="preview"></div>
77
78 <!-- COLOR -->
79 <label>Warna Lampu</label>
80 <input type="color" id="color" value="#ffffff">
81
82 <!-- BRIGHTNESS -->
83 <label>Kecerahan</label>
84 <input type="range" id="brightness" min="0" max="255" value="200">
85
86 <!-- SCENE -->
87 <label>Mode Pencahayaan</label>
88 <div class="scenes">
89 <button onclick="scene(255,255,255,255)"> Match</button>
90 <button onclick="scene(300,200,255,220)"> Training</button>
91 <button onclick="scene(255,0,255,255)"> Party</button>
92 <button onclick="scene(120,120,255,120)"> Relax</button>
93 </div>
94
95 <div class="footer">IoT Smart Lighting • ESP32 + P8P</div>
96 </div>
```

**Figure 1**  
Script Class Container

The page structure illustrated in Figure 1 presents a container class designed with responsive viewport configuration and contemporary visual styling, featuring gradient backgrounds, shadowed cards, and compactly arranged, intuitive button and slider

components. The interface comprises a circular power button, a color preview area, a color picker for lamp color selection, a brightness slider with a range of 0–255, and four scene buttons (Match, Training, Party, Relax), each invoking the scene() function with specified RGB values and brightness parameters. JavaScript logic manages system state (isOn), converts hexadecimal values to RGB format, and transmits data to the control.php script via a FormData object and a POST method fetch request carrying parameters on, r, g, b, and br. Additionally, the interface provides real-time visual feedback by dynamically updating the preview element's background color according to current RGB values, enabling users to verify lighting changes in real time before or as commands are transmitted to the ESP32- and PHP-based control module.

The system artifact was articulated through two principal outputs: a layered architectural design (perception–processing–communication–presentation) and a technical implementation design that maps lighting control functions to NodeMCU/ESP8266 capabilities. At the hardware level, the selection of NodeMCU based on ESP8266 is justified by the integration of Wi-Fi 802.11 b/g/n, support for Station/SoftAP modes, and provision of peripheral interfaces (GPIO, UART, I<sup>2</sup>C, SPI) along with PWM functionality essential for LED intensity and color control. Specifically, the ESP8266EX module incorporates PWM support and reference implementations for LED smart lighting demonstrations, thereby establishing a robust technical foundation for brightness and color control via PWM signaling on this microcontroller platform. Consequently, the design-and-development phase not only produced component interconnection diagrams but also ensured traceability from requirements (ON/OFF control, brightness, RGB, rapid response) to feasible hardware and software design decisions on the NodeMCU platform (Espressif.com, 2025).



**Figure 2**  
ESP8266 Module  
(source: Wikimedia Common)

Figure 2 depicts a microcontroller board that integrates the ESP8266EX-based ESP-12E Wi-Fi module with a micro-USB interface and dual-row pin headers on both sides for IoT circuit prototyping purposes. The wireless module supports IEEE 802.11 b/g/n standards operating at 2.4 GHz frequency and is typically equipped with 4 MB of flash memory for application firmware storage. The left side displays power management circuitry and a USB-to-serial converter (CP2102 or CH340) that facilitates programming and debugging via computer. This configuration renders the board well-suited for the development of low-power embedded systems, including smart lighting applications, environmental monitoring, and IoT-based automation.



**Figure 3**  
Application Interface

Figure 3 presents the interface for a Smart RGB Lighting system arranged in a unified control panel with minimalist dark aesthetics. The upper section features a lamp icon and application title, followed by a circular red power button representing the primary ON/OFF function. A rectangular preview area is provided to display the current light color. Below this are a color input component labeled "Warna Lampu" (Lamp Color) and a slider labeled "Kecerahan" (Brightness) for adjusting light intensity. The lower section contains four lighting mode buttons—Match, Training, Party, and Relax.

The developed IoT-based Smart Lighting system was successfully implemented as an artifact integrating NodeMCU (ESP8266), Wi-Fi connectivity, RGB LEDs, and the Blynk application as a control interface. This implementation was subsequently subjected to functional testing to verify the artifact's alignment with solution objectives—namely, remote control of lamp status, brightness, and color. Within the Design Science Research framework, such testing serves as an evaluation phase to assess the artifact's utility and performance in addressing the targeted problem context (Zolbanin & Aubert, 2025).

According to Table 1, the ON/OFF control function registered a "successful" status with notation indicating that the lamp responded to commands in real time. This finding suggests that the command communication path from the Blynk application to NodeMCU and the actuation process (switching) at the lamp load operated without functional impediments under test conditions. Successful ON/OFF control constitutes a critical prerequisite in field lighting systems, as it ensures that facility managers can execute rapid responses when activity requirements or field conditions change.

**Table 1. Implementation of NodeMCU-Based IoT Smart Lighting System**

Parameter	Result	Remarks
Lamp ON/OFF Control	Successful	Lamp responds to commands in real time
RGB LED Color Adjustment	Successful	Color matches Blynk application input
Brightness Adjustment	Successful	Light intensity can be adjusted
Wi-Fi Connection	Stable	No disconnections occurred during testing
System Response	Rapid	No significant latency detected

For the RGB LED color adjustment function, Table 1 indicates a "successful" result, with colors reported as consistent with Blynk application inputs. This confirms that the system reliably translates color parameters from the application interface into RGB LED output compositions across the test scenarios conducted. From an iterative prototyping perspective, the congruence between color output and input constitutes evidence that user requirements regarding lighting ambiance flexibility have been validated at the prototype stage.

The brightness adjustment function was likewise designated "successful," with notation indicating that light intensity can be modulated. From an applied standpoint, brightness control affords opportunities for energy efficiency and illumination level adaptation according to activity type (training, competition, or recreational activities), although quantitative energy consumption measurements have not yet been reported in the present draft. Consistent with DSRM evaluation principles, these results warrant further elaboration in subsequent article versions through measurable metrics (e.g., tested PWM levels, intensity stability, and potential flicker) to enable more objective artifact quality assessment.

Regarding connectivity, Table 1 records Wi-Fi connection as "stable" and system response as "rapid" without significant latency. This finding is significant because IoT system performance is heavily influenced by network reliability; unstable connections can disrupt real-time control and diminish system dependability in actual deployment. In accordance with DSRM reporting practices, the results section should supplement categorical descriptors ("stable/rapid") with numerical log data (e.g., average latency per command, uptime percentage, and reconnection count), thereby strengthening the study's scientific contribution and facilitating replication.

The technical and functional evaluation inherently represents evaluation characteristics that are not only formative (for refinement) but also summative (assessing final viability), examining key properties of relevance—namely, control functionality (ON/OFF, brightness, color), Wi-Fi connection reliability, and perceived system responsiveness. This strategy aligns with the FEDS (Framework for Evaluation in Design Science) framework, which emphasizes that DSR evaluation must be designed to address "why, when, how, and what to evaluate," and may integrate artificial evaluation (controlled testing) and naturalistic evaluation (testing in usage contexts) according to design risk and research resources (Baskerville et al., 2026). In the context of this research, the test result summary in Table 1 can be positioned as an evaluation demonstrating artifact utility.

## CONCLUSIONS AND SUGGESTIONS

This research successfully satisfied success criteria at both functional and design levels. All primary features—ON/OFF control, brightness adjustment, and RGB LED color adjustment—operated according to specifications and performed consistently across test scenarios, supported by stable Wi-Fi connectivity and rapid system response as summarized in the results table. From a design success perspective, the layered architectural design and implementation on NodeMCU/ESP8266 with the Blynk interface demonstrate adherence to established IoT system development practices (leveraging integrated Wi-Fi connectivity, command-to-actuation mapping, and PWM-based intensity/color control), thereby constituting a feasible solution for sports facility contexts. Moreover, this research fulfills contribution success criteria by introducing a more interactive smart lighting implementation (including color control) in volleyball court facilities—a domain that has received relatively less attention compared to smart homes or commercial buildings—while simultaneously providing methodological reference for artifact development based on iterative prototyping.

Nevertheless, to ensure more robust and measurable fulfillment of performance success criteria (e.g., target average response time <1.5 seconds and connection stability >98% during sustained operation), future research should incorporate quantitative metric reporting derived from log data, such as mean and distribution of per-command latency, Wi-Fi uptime percentage, reconnection event counts, and stress testing over extended durations under varying network interference conditions. Subsequent development may also integrate sensor-based automation (light/motion sensors) and scheduling (timers) so that the system becomes not only reactive to user commands but also adaptive to usage contexts, along with energy consumption measurements to numerically validate efficiency benefits. From a practical contribution standpoint, trials at larger installation scales (greater numbers of lamp points/court areas) and user experience evaluation (e.g., application operation ease and feature requirements) will enhance readiness for real-field implementation and strengthen the generalizability of research findings.

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