Cloud-Integrated UV Lamp Monitoring and Control System

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ABSTRACT— Arklite's air treatment systems come with an integrated digitized interface which monitors run hours of every lamp, on/off cycles, and alerts of any errors which are shown on an LCD screen. For better performance of the system and remote access capability, it is suggested that an IoT-based communication solution be implemented via an Android app using an ESP32 board. These air treatment devices are crucial in ensuring that the room is free of pollutants. Although, the systems in question offer no remote access to data since operation data is only displayed on local LCD panels, which hinders maintenance through foresight. The aim of this paper is to create an air treatment system integrated with the cloud that utilizes IoT concepts with an ESP32 microcontroller for real-time data surveillance and remote access via mobile application. The system collects the parameters of the UV lamps from the control panel and sends them through Wi-Fi to the ThingSpeak cloud. The Android application built from Flutter downloads the information and processes it, thus, enabling the users to view and manage the lamp's operations. Users are granted access through Firebase Authentication which offers protection. In this case, smart air treatment systems equipped with IoT technology are easier to access, more reliable, and efficient.

Keywords: *ESP32, IoT, Ballast, Android Application, Cloud Integration, ThingSpeak, Air Purification, Remote Monitoring.*

1. INTRODUCTION

Ultraviolet (UV) lamps are an important component of air treatment equipment which provides efficient disinfection and cleaning by killing airborne microorganisms including bacteria, viruses, and fungus. UV lamps have a highly significant function to ensure indoor air quality through suppression of growth of mold, bacteria, and other pathogenic microorganisms on the cooling coils. This monitoring of critical parameters like light run hours, on/off condition, and error messages is critical for ensuring maximum efficiency. Currently, an LCD display and digital control panel are utilized for on-line monitoring of Arklite's UV-based air treatment systems. Indoor air quality has significant effects on human health, as allergies, respiratory issues, and other illnesses have been attributed to substandard air quality [6]. By removing impurities, air treatment systems can minimize these risks; however, traditional systems rely on local LCD displays to monitor system breakdowns, UV lamp operating hours, and ON/OFF status. These traditional monitoring techniques involve manual checks, which restrict the efficiency of proactive maintenance[8].The Internet of Things (IoT) has transformed remote monitoring by allowing real-time data transmission and cloud integration[10].The ESP32 microcontroller is a low power usage solution for IoT-based applications of low power usage, embedded Wi-Fi, and real-time processing and has been successfully applied in many smart systems such as home automation and environmental monitoring [7][11][12].This project proposes the development of a Cloud-Integrated UV Air Treatment System on the ESP32 microcontroller and mobile app in Flutter, using its low power consumption, integrated Wi-Fi functionality, and real-time processing efficiency.

The system utilizes ThingSpeak as a cloud communication interface for data storage and visualization of operating data as a user-friendly interface for monitoring the health of the system and remote controlling of UV lamps.

This integration increases the system's reliability, reduces maintenance activities, and facilitates predictive maintenance, eventually increasing the overall efficiency of UV-based air treatment systems.

1.1 Problem Statement

Traditional UV lamp monitoring systems in air cleaning systems use local control panels and LCD displays and need to be physically inspected to monitor lamp usage, operational condition, and system faults. Such a method is inefficient, not real-time remote accessible, and prone to delayed maintenance or undetected failures. With the mounting industrial needs for predictive maintenance and automation, there is a pressing need for an intelligent, IoT-enabled solution with real-time monitoring, remote control, as well as automated error detection.

1.2 Objectives

The major goals of this research are:

1. To create an ESP32 IoT-based system for the monitoring of air purifiers.
2. To have real-time cloud communication through ThingSpeak for wireless secure data transmission.
3. To design and implement an Android application via Flutter for monitoring and controlling UV lamps employed in these systems.
4. To show the working condition, on/off time, and error notifications concerning the UV lamp on a user-friendly interface.
5. To provide secure and reliable wireless communication.

2. LITERATURE SURVEY

Assessment of an Air Purifying Device with Filtration and UV [1] In this study, a prototype air-cleaning device that incorporates multi-layer filtration and ultraviolet-C (UV-C) lamps was assessed for indoor air cleaning. The device successfully removed almost 100% of culturable airborne bacteria and as much as 97% of particulate material. The integration of filtration and UV-C treatment showed a strong two-layer system for enhancing indoor air quality, with great potential for disease prevention in indoor environments. Ultraviolet Air and Surface Treatment [2] This article emphasizes the use of ultraviolet germicidal irradiation (UVGI) in airborne pathogen control and clean surface maintenance, especially in healthcare and commercial environments. It addresses different UVGI systems, such as upper-air UV, in-duct UV, and surface disinfection systems. UVGI enhances the quality of air and saves energy and maintenance while being safe if applied with guidelines. The research highlights UVGI as a means of controlling infection as well as the efficiency of HVAC systems. Undesired Indoor Air Quality Impacts of Applying Ultraviolet Lamps for Disinfection [3]. This article investigates the unintended effects of applying high-intensity UVC equipment on indoor air quality (IAQ). The research has discovered that the use of UVC irradiation causes elevated levels of fine particle concentration and indoor air chemical transformations such as the increased concentration of volatile organic compounds (VOCs) and oxidation products. The transformations present a health concern when rooms are occupied shortly following disinfection. The results draw attention to elaborate investigations on environmental effects of UVC disinfection systems. Design of an IoT Air Disinfection Machine Control System [4]. The following paper discusses an IoT-based control system for an air disinfection machine. The system incorporates the ESP32 microcontroller to combine air quality sensors, a UV sterilization lamp, ozone generators, and HEPA filters for real-time monitoring and disinfection. The device can be controlled by users through a cloud-connected mobile application. Lab testing in a controlled environment revealed vast improvements in air quality, and the system was found to automatically react to shifting air quality indices. The design demonstrated efficiency in reducing pollutants and pathogen Development of an IoT-Enabled Air Pollution Monitoring and Air Purifier System [5]. This study introduces an IoT-enabled air purification and monitoring prototype using Raspberry Pi 3 B+, PMSA003 sensors, and gas sensors (MQ2 and MQ135). The system uses a multi-stage filtration process (pre-filter, activated carbon filter, and HEPA filter) to purify air, targeting particulate matter and gaseous pollutants.

Sensor data is transmitted to the ThingSpeak Cloud platform every 15 seconds for real-time analysis. Experimental tests under normal, combustion, and smoke conditions validated its ability to significantly reduce air pollutants. The system met ISO 9 cleanroom standards and achieved high filtration efficiency, showing potential for applications in healthcare, industry, and environmental monitoring. An IoT-Based Handheld Environmental and Air Quality Monitoring Station [10]. This paper presents the development of an IoT-based handheld environmental monitoring station as part of an extended data acquisition system. The station is composed of five different sensors and uses an ESP8266 (NodeMCU) microcontroller to offer Wi-Fi connectivity. Data is communicated to ThingSpeak every 30 seconds and can be accessed using a handheld monitor or a mobile app developed using Android Studio. JSON is used in REST API communication and MySQL is used in data storage, demonstrating real-time environmental monitoring and mobile connectivity. Home Automation Using Wi-Fi: ESP32-Based Remote Control and Environmental Monitoring System [11].

This project introduces an end-to-end home automation system using Wi-Fi and ESP32 microcontrollers for easy device control and monitoring. DHT11 sensors and relay modules are used to enable environmental sensing and device interaction. It is controlled using a mobile app interface, with easy user interaction. It is energy-efficient and automated with reliability and responsiveness proven by testing. Design of an ESP32-Based IoT Smart Home Automation Management System [12]. In this work, an ESP32-based smart home management system powered by rechargeable DC batteries is proposed. The system includes LCD feedback, occupancy control, temperature-controlled fan switching, and remote alarming via Wi-Fi and mobile phones. It illustrates how IoT and embedded systems can be utilized in intelligent control and energy-saving smart automation of homes.

3. METHODOLOGY

Our Cloud-Integrated UV Monitoring with ESP32 incorporates a systematic approach to achieve perfect IoT integration, real-time monitoring, and safe data transfer. The system is implemented with the ESP32 microcontroller connected with the relay module and control panel to receive the operational parameters. The software for the ESP32-based air treatment system is developed using Arduino Studio in Flutter. ESP32 executes the hardware operations and is operated through Wi-Fi of the device. The Android app on the other hand provides controls to the operations and displays the required parameters through a user-friendly interface. All the communication between the hardware and software is recorded and monitored on the ThingSpeak Cloud platform. The implementation consists of system design in the block diagram and flowchart given below.

3.1 System Design

This is the conventional UV air treatment system developed by Arklite, which uses a DCP Board, Relay Board, Ballasts, and UV Lamps for air purification. It operates on 230V AC input and includes a digital control panel (DCP) with an on/off switch and communication cable for system control.

The system has an ON-OFF switch for easy hand use and Connectwell connectors to enable easy electric connection between modules. The ON/OFF switching of the UV lamp is important and is managed by the relay board. It gets commands from the DCP board to turn ON or OFF the ballasts, which regulate the supply voltage to the UV lamps. The ballasts supply appropriate voltage and current to the lamps to operate. The wiring diagram is scalable to the point that the number of ballasts and lamps is not fixed (e.g., 2, 4, 6, or 8 lamps), but the same connection scheme applies.

Every UV lamp is wired by a 5-meter, 4-core cable, which permits flexibility but maintains a standard wiring technique. The Fig.1 Below illustrates Block Diagram of UV air treatment system designed by Arklite Specialty Lamps Pvt. Ltd.

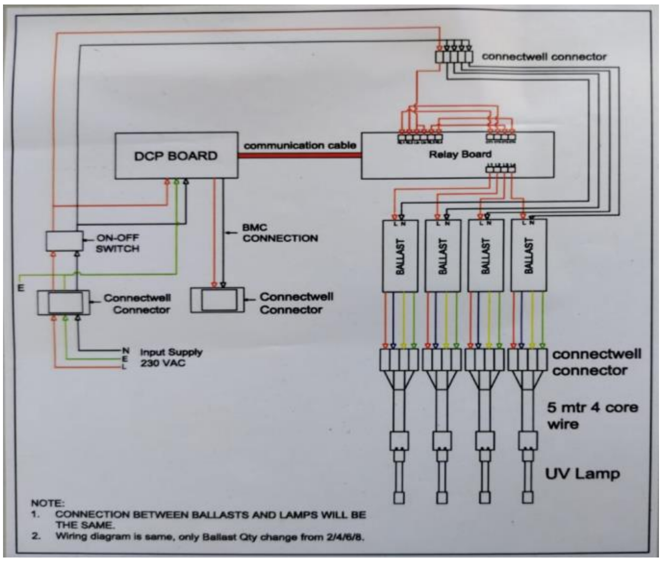

Fig.1 System Design

3.2 Proposed System Design

With this configuration, a smartphone is being used as the user interface to send commands wirelessly over Wi-Fi. The ESP32, a general-purpose microcontroller that comes equipped with Wi-Fi, reads these commands and translates them so that it can control the relay board, an electronic switch. The relay board is employed to switch ON and OFF the UV lamp according to the instructions received. A power supply unit provides the necessary electrical power to the relay board and the lamp so that the process can be kept continuous. The system eliminates the need for human intervention, with real-time remote monitoring and control of the UV lamp. With the use of IoT technology, the system enhances efficiency, accessibility, and automation and hence it is more reliable compared to conventional control systems.

To make the system simple and readily accessible, we created a mobile app with Flutter, one of the popular cross-platform app development frameworks. The app is made clean and minimal, such that anyone—even without technical expertise—can view and control the UV lamps real-time. Once the user logs in, the app establishes a connection to ThingSpeak, a cloud platform wherein the ESP32 microcontroller sends the current status of the lamp. This comprises data such as whether the lamp is ON or OFF, and if there are any faults. The app employs ThingSpeak's Read API to retrieve this information and present it in a readable format.

Apart from monitoring, the app also enables users to remotely turn the lamp ON or OFF by sending commands via ThingSpeak's Write API. To ensure only valid users have access, we integrated Firebase Authentication, which handles user registration, login, and logout securely. This gives us peace of mind without sacrificing the interface to be smooth and clean. The goal was to create a system that does not just work—but works in a way that is easy, smart, and useful for real users. The following Fig.2 Shows the Block Diagram of the proposed system.

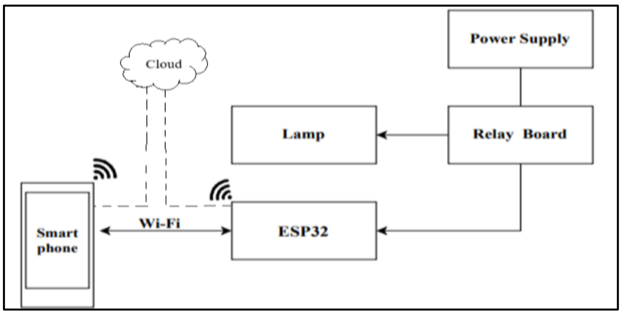

Fig.2 Proposed system Block Diagram

3.3 Flow Chart

This flowchart illustrates how data is retrieved from a device and displayed on a smartphone via an ESP32 microcontroller and Wi-Fi. The process starts with retrieving data from a device, which is processed via the ESP32. The ESP32 attempts to send this processed data via Wi-Fi. If the Wi-Fi connection is established, the data is shown on a smartphone. When the connection fails, the ESP32 attempts again, sending the data once a connection is made. This system illustrates a simple Internet of Things (IoT) application where data is obtained, processed, and wirelessly communicated for monitoring or control on a smartphone. The Flowchart Fig.3 indicates the flow associated to a project working.

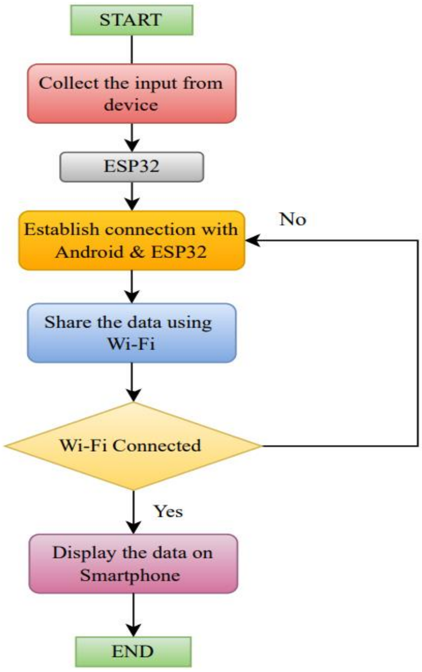

Fig.3 Flow Chart

3.4 Integration of system

This project integrates different hardware and software elements to develop a smart UV lamp control and monitoring system, with the ESP32 microcontroller at its core. The system is internet-enabled through Wi-Fi, enabling users to control and monitor the UV lamp remotely using a mobile application developed using Flutter. Data transmission and storage are managed through ThingSpeak, an IoT cloud platform.

The ESP32 serves as the primary controller, receiving instructions from the mobile app and triggering the relay module to power on or power off the UV lamp. The relay is an electronic switch which assumes control over the lamp's electrical supply based on inputs over the network.

For manual and automatic operation, a Digital Control Panel (DCP) is incorporated in the design. It communicates with a Relay Board to enable the control of multiple UV lamps in parallel. A physical ON/OFF switch is also provided for local operation, enabling flexibility in case of failure in connectivity or on-site maintenance.

All the UV lamps in the system are connected to a ballast, which delivers a stable and controlled current to the lamp. Wiring is spliced with Connectwell terminal connectors and is held firm in position to establish safe proper electrical connections. The system operates on a 230V AC supply, which is safely distributed and stepped down as necessary to power components.

One of the basic building blocks of this system is the Flutter mobile application that has been created to offer a smooth and effortless experience to the user. Users can use the application for:

- Checking whether the UV lamp is ON or OFF.
- View total working hours of the lamp.
- Get real-time fault notifications/alerts.
- Turn the lamp ON or OFF remotely.
- Secure authentication using Firebase Authentication.

The application communicates with ThingSpeak through API requests to obtain the latest data and display it in real time. Since the application is constructed using Flutter and Dart, it is optimized for Android and iOS and can simply be upgraded to support future changes to support feature items such as multi-light control or even analytics views.

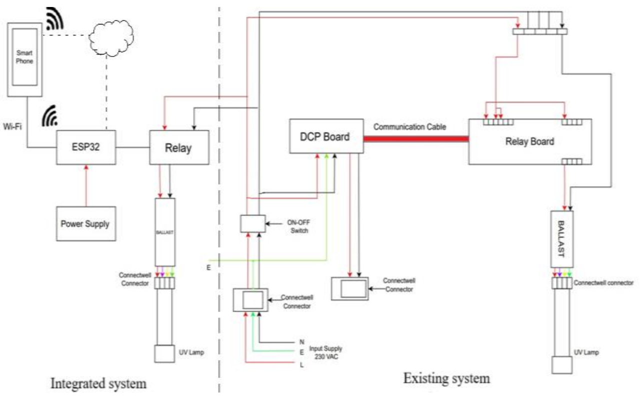

Fig.4 Proposed system Block Diagram

4. RESULTS

This picture depicts an online control interface for UV Lamp Control within the Arklite Specialty Lamps Pvt. Ltd. It is accessed via a local IP address (192.168.223.235/on), which means it runs within a private network.

The interface displays the status of the UV lamp as "ON", in green. Under the status, the ON time is shown as 0 minutes, indicating that the lamp has just been switched on or the timer has not yet begun. The interface offers two buttons:

- Green "Turn ON" button: Probably utilized to turn the UV lamp ON.
- Red "Turn OFF" button: For turning the UV lamp OFF.

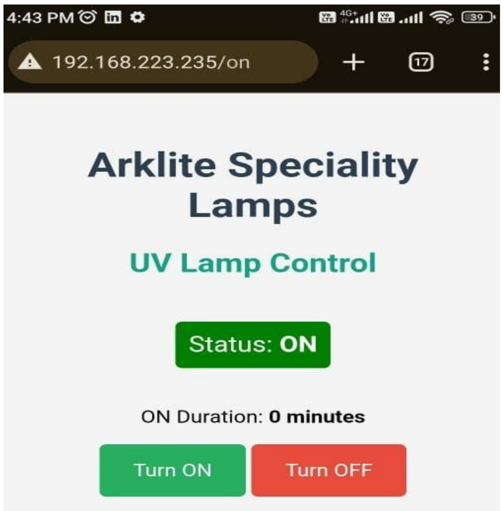

Fig.5 Web-based control interface

The LCD screen on the control panel gives real-time status information for the operation of the UV lamp. It indicates the lamp number, its current status (ON or OFF), and the time for which it has been operating.

Fig.6 LCD display on the control panel

4.1 Result Table

Timestamp	Lamp ID	Status	ON Duration (hh:mm:ss)
2025-03-06 10:00	Lamp 1	OFF	00:00:00
2025-03-06 10:15	Lamp 1	ON	00:15:00
2025-03-06 10:30	Lamp 1	ON	00:30:00
2025-03-06 10:45	Lamp 1	ON	00:45:00
2025-03-06 11:00	Lamp 1	OFF	00:45:00
2025-03-06 11:15	Lamp 1	OFF	00:45:00
2025-03-06 11:30	Lamp 1	ON	01:00:00
2025-03-06 11:45	Lamp 1	ON	01:15:00
2025-03-06 12:00	Lamp 1	OFF	01:15:00

Fig.7 Result Table

The table illustrates live monitoring of the status of the lamp as well as its cumulative ON duration. Each row logs a timestamp, the ID of the lamp, its status (ON/OFF), and the cumulative time for which the lamp has been ON since its initial activation. Initially, the lamp is OFF at 10:00 AM with zero runtime. At 10:15 AM, the lamp is turned ON, and its runtime begins to accumulate.

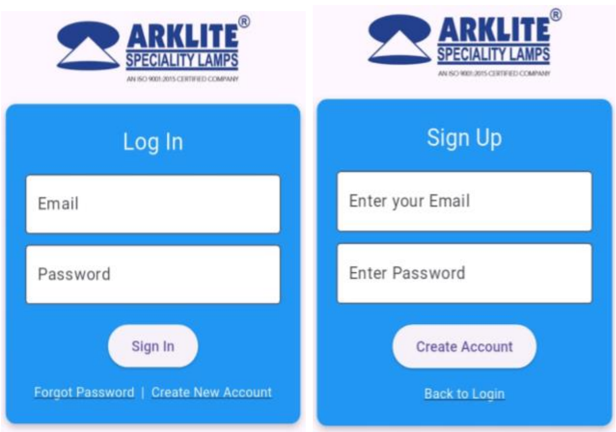

Fig. 8 (a) Login and Sign-Up pages

Fig. 8 (b) Home Page of App

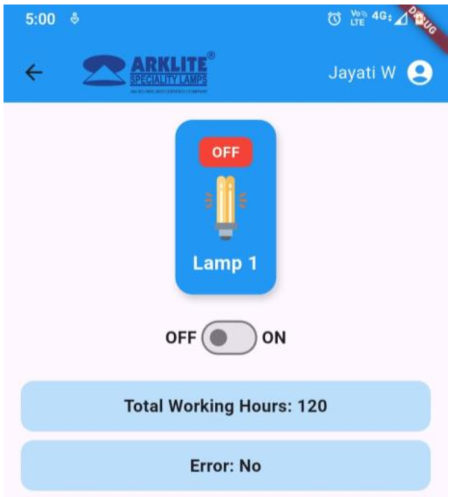

Fig. 8 (c) Individual Lamp Screen

The Android app built under this project provides an easy and intuitive interface that is able to effectively connect to the cloud and remotely control the UV lamps in real-time. Once users are logged in, they are able to see the status of all lamps connected on a dashboard. The lamp card indicates whether the lamp is ON or OFF, and with a simple tap, users can remotely switch them on or off. On the press of any lamp, a screen with all the working hours and the errors that are found appears in detail, facilitating timely maintenance. The app is also able to support login and signup so that the app can be used by several users. On the whole, the app facilitates real-time monitoring, immediate control, and seamless communication between the user and the system, achieving the primary aim of minimizing manual efforts and increasing system reliability.

5. CONTRIBUTION OF THE PROJECT

This project contributes to the advancement of IoT-based monitoring systems by integrating wireless communication into Arklite Specialty Lamps Pvt. Ltd. UV lamp air treatment systems. This includes:

1. Real-Time Monitoring and Control: The system provides continuous monitoring of the status of UV lamps, run hours, ON/OFF control, and error detection remotely.

2. Easy-to-Use Interface with Cloud Integration: The user has an easy-to-use interface with a mobile application that allows easy integration with the cloud to view data and notifications.

3. Automaton of Air Treatment System: Enhances the UV lamp system of Arklite through automating diagnosis and reducing manual intervention.

6. CONCLUSION

This work introduces an effective IoT-based UV lamp control and monitoring system for air treatment processes to ensure air hygiene and inhibit microbial growth. Through the integration of the ESP32 microcontroller with the Digital Control Panel (DCP), the system facilitates real-time monitoring of lamp status, operating time, and fault notifications while providing secure data transmission.

The solution provides remote access to the web and Android apps, with remote monitoring and control of UV lamps from anywhere. The app has simple login/register pages and instant feedback, making the system more responsive and easier to use.

In addition to technical effectiveness, the system maintains such important zones as schools, labs, and hospitals at higher levels of air quality through predictive maintenance that powers the use of renewable energy. The initiative demonstrates the ability of IoT to rethink legacy systems as intelligent automated platforms for industrial efficiency and enhanced public health.

7. ACKNOWLEDGMENT

This project is performed under the MOU with Arklite Speciality Lamps Pvt. Ltd. and is an interdisciplinary effort among students of Electronics & Telecommunication Engineering and Computer Engineering (Regional Language) departments of PCCOE, Pune. The project was performed under the mentorship of internal project guides from both departments and an external industry mentor Dr. Mandar Sahasrabudhe, General Manager from Arklite Speciality Lamps Pvt. Ltd.

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