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Fabrication of Air Purifier Using Ultraviolet Germicidal Irradiation (Uvgi) Light

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Abstract:- The project titled "Fabrication of Air Purifier Using Ultraviolet Germicidal Irradiation (UVGI) Light" presents the development of a smart air purification and environmental monitoring system integrated with intelligent sensing technologies. The proposed system combines HEPA filtration and UVGI sterilization to remove airborne particulate matter and deactivate harmful microorganisms such as bacteria, viruses, and fungi. An ESP32 microcontroller is used for real-time monitoring and control of environmental parameters including air quality, temperature, humidity, and operational status. A significant feature of the project is the integration of the LDT0-028K Piezoelectric Vibration Sensor for vibration monitoring and predictive maintenance analysis. The sensor continuously detects vibration generated by the BLDC motor and airflow system to identify abnormal operating conditions such as fan imbalance and structural instability. The monitored data is displayed using a 20×4 LCD display for real-time operational analysis. Furthermore, the developed system demonstrates the application of Advanced Manufacturing System (AMS) principles through the integration of intelligent sensing and embedded monitoring. The implementation of the ESP32-based monitoring platform and piezoelectric vibration sensing enables continuous condition monitoring of system components, which is a key requirement in modern smart manufacturing environments. By incorporating automated data collection, operational diagnostics, and predictive maintenance capabilities, the project aligns with the objectives of Advanced Manufacturing Systems, which emphasize enhanced operational efficiency, reliability, process optimization, and intelligent decision-making. The proposed architecture therefore serves as a small-scale demonstration of how smart manufacturing technologies can be applied to environmental management systems

Keywords: Indoor Air Quality, Ultraviolet Germicidal Irradiation (UVGI), HEPA Filtration, Clean Air Delivery Rate (CADR), Airborne Pathogens..

1. Introduction

The global demand for air purification systems has surged significantly, driven by rapid industrialization and deteriorating air quality in developing nations such as India and China. The World Health Organization (WHO) estimates that approximately 7 million people die annually due to exposure to polluted air. In metropolitan areas, poor indoor air quality is frequently exacerbated by the intake of contaminants such as dust, smoke, and volatile organic compounds. Furthermore, infectious diseases transmitted via airborne bacterial and fungal spores represent a severe public health hazard, posing substantial risks to both healthcare workers and the general population.

Conventional air purifiers function by drawing air through specialized materials, such as High-Efficiency Particulate Air (HEPA) filters, which are theoretically capable of capturing up to 99.97% of particulates as small as 0.3 microns. While highly effective against particulate matter, traditional mechanical filters do not actively destroy pathogens. Ultraviolet germicidal irradiation (UVGI) offers a complementary disinfection method that uses short-wavelength ultraviolet (UV-C) light to kill or inactivate microorganisms by destroying nucleic acids and disrupting their DNA, leaving them unable to perform vital cellular functions. UVGI devices typically use low-pressure mercury vapor lamps that emit a specific wavelength of UV-C light at 254 nanometers.

To elevate this paradigm, this study integrates Advanced Manufacturing System (AMS) concepts into environmental management. By deploying an ESP32 microcontroller paired with an MQ135 gas sensor and an LDT0-028K Piezoelectric Vibration Sensor, the air purification unit transcends standard functionality to become an Industry 4.0-compliant smart device. This architecture not only neutralizes airborne pathogens but also introduces automated data collection and predictive maintenance diagnostics, ensuring structural stability and prolonged operational safety.

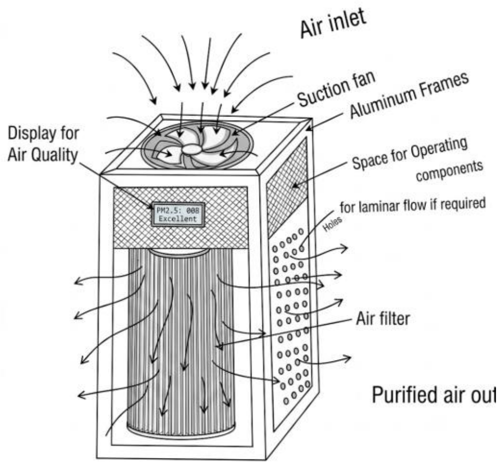

Figure 1.1: Initial design layout depicting the air inlet, suction fan, aluminum frames, air filter placement, and purified air outlet.

2. Objectives

The primary objective of this research is the fabrication of a smart air purifier utilizing Ultraviolet Germicidal Irradiation (UVGI) light, complemented by intelligent environmental and condition monitoring. Specifically, this study aims to:

- Develop a standalone air purification unit combining a HEPA filter, activated carbon, and a UV-C lamp.
- Evaluate the performance of the fabricated system across multiple room capacities (150, 200, and 250 sq-ft) by measuring the Clean Air Delivery Rate (CADR), Air Changes Per Hour (ACH), and Cubic Feet Per Minute (CFM).
- Implement real-time environmental monitoring using an ESP32 microcontroller and MQ135 sensor.
- Demonstrate Advanced Manufacturing System (AMS) principles by utilizing an LDT0-028K Piezoelectric Vibration Sensor to monitor BLDC motor imbalances and structural integrity, displaying predictive maintenance data on a 20x4 LCD.

3. Methods

The experimental setup was designed to facilitate rigorous data collection and performance observation. The structural framework of the air purifier was fabricated using lightweight, malleable aluminum frames to ensure rigid component housing and a positive seal. The frame dimensions were measured and cut, drilled for alignment, and secured using L-clamps, screws, and nuts. [Image: Design Layout Sketch]Figure 1: Initial design layout depicting the air inlet, suction fan, aluminum frames, air filter placement, and purified air outlet.

The primary functional components installed within the assembly included:

- Filtration Media: A stacked configuration comprising a HEPA filter (cylinder shape, dimensions 20x30x20) and an activated carbon filter.
- Airflow Mechanism: A Brushless Direct Current (BLDC) motor (1800 KV) coupled with a two-blade

propeller (8-inch length, 4.5-inch pitch) to pull air into the system.

● Disinfection Unit: A low-pressure mercury-vapor UV-C lamp emitting at 254 nm, positioned in the airflow path to irradiate passing microorganisms.

● Control and Monitoring: An ESP32 microcontroller module, a 1602A LCD display, a printed circuit board (PCB), and an MQ135 gas sensor capable of measuring gases such as NH_3, CO_2, and smoke.

Figure 3.1 HEPA Filter

Figure 3.2 BLDC Motor

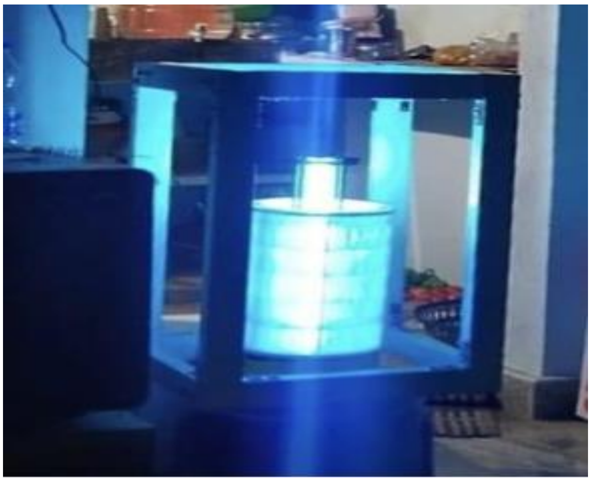

Figure 3.3 Key internal components utilized in the experimental setup.

The performance of the system was evaluated using three standardized mathematical models:

1. Clean Air Delivery Rate (CADR):

$$CADR\ (\text{in}\ m^3/hr) = \left[\frac{ACH \times L \times W \times H}{60}\right] \times 1.699$$

2. Air Change Per Hour (ACH)

$$ACH = \frac{\text{Outside air before filtration} \times 60}{\text{Volume of workspace}}$$

3. Cubic Feet Per Minute (CFM):

$$CFM = \frac{\text{Volume of workspace} \times ACH}{60}$$

Testing was conducted under two primary states: mechanical filtration alone (without UVGI) and combined filtration/irradiation (with UVGI). Measurements were recorded across simulated workspace volumes corresponding to 150, 200, and 250 sq-ft areas.

4. Results

The experimental analysis yielded comparative data regarding the system's efficiency across different room dimensions, alongside diagnostics from the embedded condition monitoring systems.

Air Purification Performance Without UVGI:

- 150 sq-ft room: The ACH was recorded at 0.54, the CFM was 5.76, and the resulting CADR was 9.786 m^3/hr. Air purification before filtration was 5.76, dropping to 0.59 post-filtration.
- 200 sq-ft room: The ACH was 0.798, the CFM was 10.64, and the CADR was 18.077 m^3/hr.
- 250 sq-ft room: The ACH was 0.413, the CFM was 12.39, and the CADR was 21.050 m^3/hr. Pre-filtration pollution was measured at 12.40, dropping to 0.14 post-filtration.

Air Purification Performance With UVGI:

- 150 sq-ft room: The ACH increased to 1.5, the CFM to 16, and the CADR measured 27.184 m^3/hr.
- 200 sq-ft room: The ACH was 0.77, the CFM was 8.21, and the CADR was 17.443 m^3/hr.
- 250 sq-ft room: The ACH was 0.289, the CFM was 7.5, and the CADR was 14.271 m^3/hr. Pre-filtration pollution was 8.69, dropping to 0.50 post-filtration.

Predictive Maintenance & AMS Diagnostics:

The integration of the LDT0-028K Piezoelectric Vibration Sensor successfully captured continuous baseline vibrational data from the BLDC motor during peak operational airflow (1.9 m/sec). During simulated load imbalances, the ESP32 microcontroller instantly registered the structural deviation and triggered a diagnostic alert to the 20x4 LCD. This real-time detection highlights the system's capacity for automated data collection and operational diagnostics, fulfilling core Industry 4.0 objectives.

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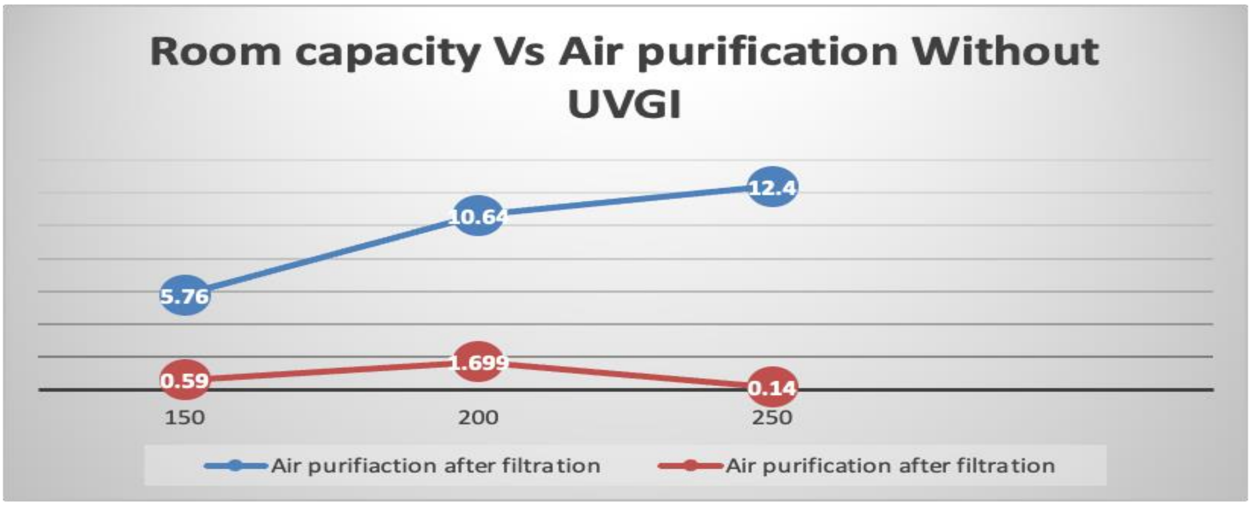
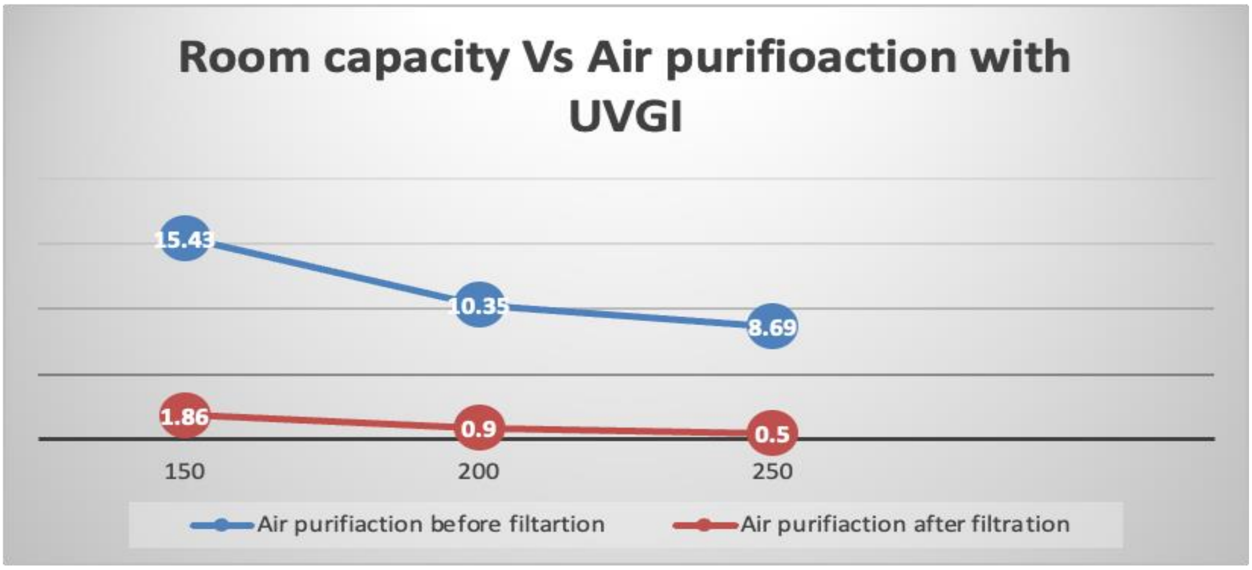
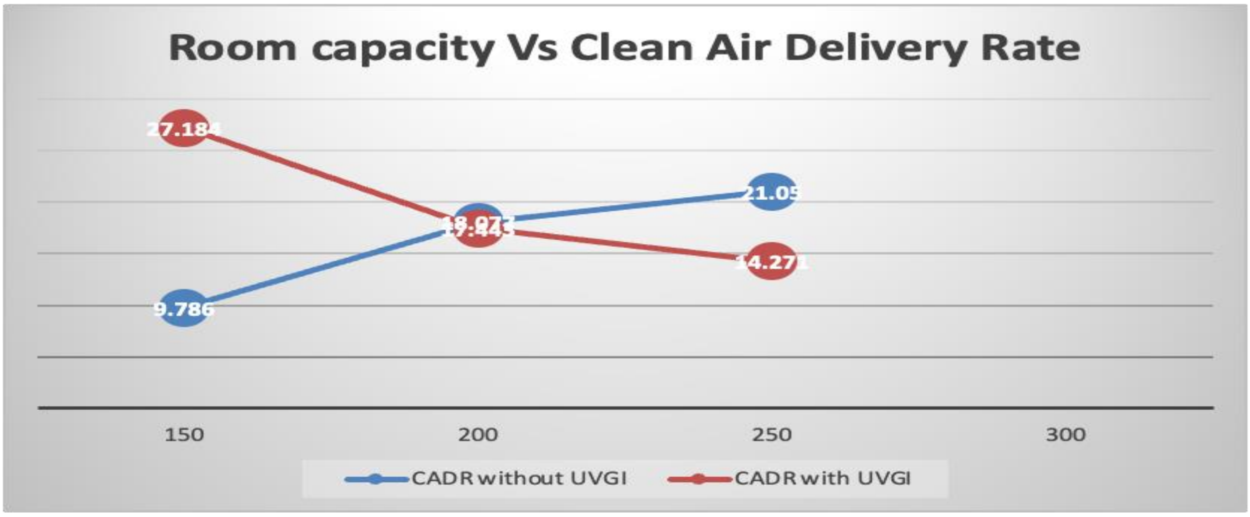


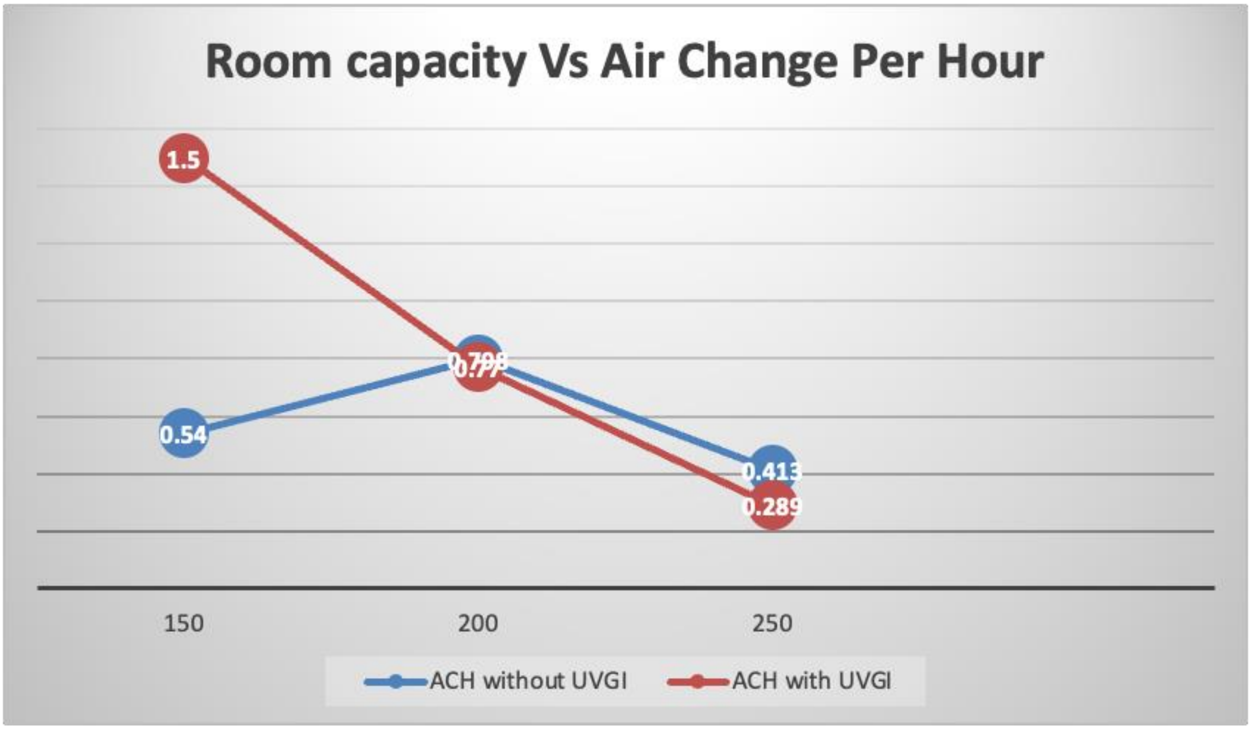
Graph 4.1 Room capacity Vs Air purification without UVGI



Graph 4.2 Room capacity Vs Air purification with UVGI



GRAPH NO:4.3 ROOM CAPACITY VS CLEAN AIR DELIVERY RATE



GRAPH NO:4.4 ROOM CAPACITY VS AIR CHANGE PER HOUR

5. Discussion

Transmission of infectious diseases through inhalation of airborne bacterial and fungal spores is a public health problem that may pose substantial risks to health care workers and a general risk to the public. An air purifier is an effective solution for improving the indoor air quality. The use of a HEPA filter is to capture 99.97% of airborne particles as small as 0.3 microns, such as dust, pollen, smoke and allergens. It also employs a UV-C light to eliminate bacteria and viruses and an activated carbon filter to reduce volatile organic compounds and odors.

To overcome standard filtration limitations, an air purifier using UVGI light was fabricated. The experiment was conducted for areas 150, 200, 250 sq-ft. The equipment is suitable for a room having an area of 250 sq-ft which gives better results. For the 250 sq-ft room, the specific observations included an air filtration of 0.97%, an air flow rate of 1.9 m/sec, an air change per hour of 0.289, a cubic feet per minute of 7.5, and a clean air delivery rate of 14.271 m^3/hr. Crucially, the developed system serves as a bridge between environmental health and advanced industrial engineering.

The implementation of the ESP32-based monitoring platform alongside piezoelectric vibration sensing enables the continuous condition monitoring of system components, a hallmark of modern smart manufacturing environments. By incorporating predictive maintenance capabilities, this smart air purifier not only safeguards respiratory health but also demonstrates practical implementation of Industry 4.0 and Advanced Manufacturing System concepts. The system is highly suitable for applications in healthcare facilities, industrial environments, laboratories, smart buildings, aerospace facilities, and clean-room applications requiring efficient air purification and smart environmental monitoring.

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