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Disinfection of Room using UV-C Sanitization Robot (UV-PAUS)

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Abstract: ***In the COVID-19 pandemic situations, where Cleanliness, Sanitization are critically important and "0-contact/No contact" is the need of mankind our project provides a solution with 99% disinfection and 0-human contact where the safety of every individual is guaranteed. Our robot uniquely possesses the 'Shadow area coverage' ability. The project focuses on complete and total disinfection of the site to prevent the spread of a wide range of infectious diseases, To avoid and minimize direct human contact in the sanitization process in Covid-19 pandemic situation, Ensuring on-site safety of the sanitization authorities during disinfection of the biologically contaminated site, cover and disinfect all the possible human touched spots to eliminate and neutralize the threat of infection including the blind spots and shadow regions of the conventional sanitization methods. The project work puts forth a solution with our robot's name UV-PAUS, a remotely operated Mobile App controlled wireless Robot. A complete & trustworthy sanitization solution based on certified UV-C Light sources capable of neutralizing the 100+ biological infectious bacteria and virus threats. Mobile App-based joystick for wireless control of the robot ensuring safe distance and isolation of sanitization authority from a biologically contaminated site. Live streaming into a joystick for surveillance. Use of UV-C tube lights to ensure complete sanitization***

Keywords: UV-C, Ultraviolet light, Wireless, Sanitization, Disinfection, GUV, Robot, Arduino, UV-PAUS, Human Safety, Hospital Accumulated Infections (HAI)

1. Introduction

1.1 History

UV has been used for disinfection since the middle of the 20th century[1], first and foremost when the sun's rays were investigated by the effects of viruses during the 19th century. It is used for drinking and contaminated water, disinfection in the air, treatment of fruit and vegetable juices, and countless home appliances to disinfect everything from toothbrushes to tablet computers. In research facilities, UV has been the preferred choice when buying natural safety cabinets for years and can be used indoors. In 1999 the WHO recommended UVGI (ultraviolet germicidal Irradiation) for TB (tuberculosis) and later on updated the same in 2019[2]

a) Current scenario

We were unaware of the fact that UV has been around for decades, and we now use it mainly for home and industrial cleaning purposes as water treatment plants. Focusing currently on the UV-C also known as Germicidal UV (GUV), it has vastly grown into a capable disinfection and sanitization industry. There are three main types of UV disinfection techniques based on GUV.

- Water disinfection
- Air disinfection
- Surface disinfection

Water disinfection is a major and the oldest which uses the 254nm wavelength of UV-C for disinfection against viruses and pathogens.

Air disinfection is achieved by several methods; one of them being upper room irradiation where the upper part(air) of the room is irradiated with help of UV luminaries, while the other is where irradiating air which is passed into the room from an enclosed medium, HVAC system[3].

Upper room UVGI uses wall-mounted or luminaries suspended from the ceiling disinfecting the upper room air and creating a safe passage of air for the people below [3].as shown in Fig1.

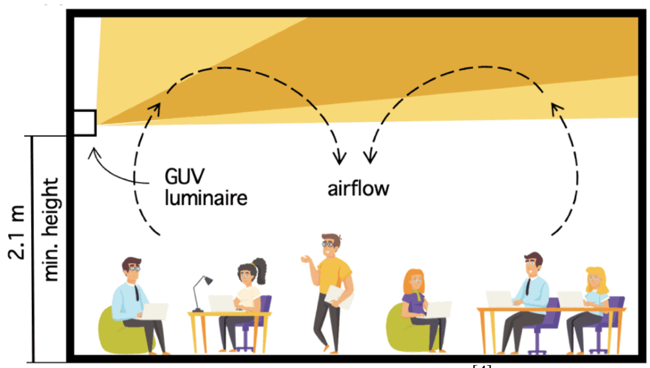

Figure 1: Upper room UVGI[4]

Duct UVGI (Fig 2.) is another means by which air disinfection is achieved. Disinfection is done by placing the UV-C luminaries in the HVAC ducts which is the main source of air into the room and it receives the decontaminated and radiated air.

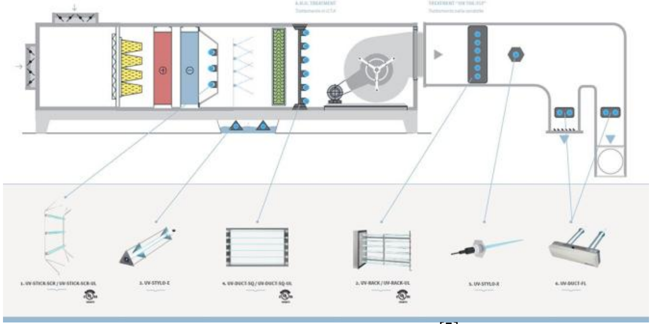

Figure 2: Duct UVGI[5]

Another area where GUV is emerging is surface disinfection which has a major role in the current COVID-19 pandemic SARS-CoV-2 which was reported to have titer decay was >99% after drop drying. UV-C irradiation efficiently reduced virus titer (99.99%), with doses ranging from 10.25 to 23.71 mJ/cm2[6] Moreover other than this UVGI has been effective against various other bacteria, spores, and pathogens[1].

Name	100% lethal Dosage (Second)	Name	100% lethal Dosage (Second)
Bacteria			
Dysentery bacilli	0.15	Micrococcus Candidus	0.4 ¨C 1.53
Leptospira SPP	0.2	Salmonella Paratyphi	0.41
Legionella Pneumophila	0.2	Mycobacterium Tuberculosis	0.41
Corynebacterium Diphtheriae	0.25	Streptococcus Haemolyticus	0.45
Shigella Dysenteriae	0.28	Salmonella Enteritidis	0.51
Bacillus Anthracis	0.3	Salmonella Typhimurium	0.53
Clostridium Tetani	0.33	Vibrio Cholerae	0.64
Escherichia coli	0.36	Clostridium Tetani	0.8
Pseudomonas Aeruginosa	0.37	Staphylococcus Albus	1.23
Virus			
Coxsackie Virus A9	0.08	Echovirus 1	0.73
Adenovirus 3	0.1	Hepatitis B Virus	0.73
Bacteiophage	0.2	Echovirus 11	0.75
Influenza	0.23	Poliovirus 1	0.8
Rotavirus SA 11	0.52	Tobacco Mosaic	16
Mold Spores			
Mucor Mucedo	0.23 ¨C 4.67	Penicillium Roqueforti	0.87 - 2.93
Oospara Lactis	0.33	Penicillium Chrysogenum	2.0 ¨C 3.33
Aspergillus Amstelodami	0.73 ¨C 8.80	Aspergillus Niger	6.67
Penicillium Digitatum	0.87	Manure Fungi	8
Algae			
Chlorella Vulgaris	0.93	Protozoa	4 - 6.70
Green Algae	1.22	Paramecium	7.3
Nematode Eggs	3.4	Blue-Green Algae	10 ¨C 40

Table 1

Table 1 illustrates the various bacteria, viruses, and algae with their respective dosages needed to inactivate them[9]. Mobile units such as UVD robots by Blue Ocean robotics[7] and Xenex germ zapper robot[8] are currently effective against the SARS CoV-2 pathogen and other deadly Hospital Accumulated Infections(HAI) playing a major role in the expansion of UV-C based surface disinfection.

b) UVGI in the future

UVGI based disinfection techniques with more research will be effective and with more autonomy into the techniques for surface sanitization, GUV will be more reliable. With a compound annual growth rate of 19% from 2020-2027 the market of UVGI which was valued to be USD 2.3 billion is projected to be USD 9.2 billion[10,11].

c) Current Disinfecting Solutions vs UV-PAUS

The primary means of sanitization and disinfection is done by chemicals such as Clorox 4 in 1 disinfectant spray and Virex 250[12] chemicals which are supposed to be diluted and then sprayed in the form of mist or either applied in a liquified state which in turn consumes more time and has greater human involvement in the entire process.

A study has shown[13] that usage of such methods has resulted in risks of mucous membrane irritation and asthma in health care workers and this is more dangerous if associated with HAI's. Using chemicals it was found that the most common problems were eye irritation(55%), neurologic symptoms(32%), and various respiratory symptoms and skin problems. Considering such harmful effects UV-PAUS is a completely single-handed device whose movements can be monitored by a camera and it serves the purpose of complete disinfection using UV-C tube lights at 254nm wavelength. By radiating the area for a certain amount of time, disinfection is achieved with 6 main luminaries providing 360º sanitization and for the shadow areas, 2 special detachable luminaries ensure that no spot is left open where a human arm cannot be reached or any blindspots left unirradiated by the luminaries during the sanitization.

2. Literature Survey

[19] P. Chanprakon, T. Sae-oung, T. Treebupachatsakul, P. Hannantanan, W. Piyawattanametha. UV sterilization technology is used to reduce the bacteria that stay on top after cleaning. The UV robot was developed by a research team based on room interest. The Robot has 19.3w tube lights illuminated in such a way that it covers a 360-degree area. The Raspberry Pi-based system was used for roaming. Test results show that a robot takes 4 times longer to disinfect the surface as there is a significant difference in the output power claimed by the manufacturer and the actual output power.

[26] S. Simmons, C. Dale, J. Holt, K. Velasquez, M. Stibich [2] The role of UV light disinfection in preventing surgical infection is introduced. How UV light-based killings prevent the spread of germs and reduce the risk of patients. The cause of the surgical site infection, safety considerations using UV Disinfection discussed, and a review of the differences in current technology.

[21] Philips lighting co. [3] Details of their TUV and UVGI (Ultraviolet Germicidal Irradiation) line of lights are provided. Detailed information of UV C tubes such as input and output wattage, voltage, current consumption, rated proportions, and their specific uses, and the proper use of each individual with important information such as solar radiation was provided.

[22] M. Hessling , K. Hönes , P.Vatter , C. Lingenfelder.[4] Coronaviruses appear to be more sensitive to UV. The maximum limit for log reduction (90% reduction) is approximately 10.6 mJ/cm2 (medium), and the actual value is only 3.7 mJ/cm2 (medium). Conclusion: Since coronaviruses do not structurally differentiate in any major discharge, SARS-CoV-2. The virus and future mutations may be more sensitive to UV so that conventional UV disinfection procedures do not use the new SARS-CoV-2 virus without further modification.

[23] C. S. Heilingloh, U. W. Aufderhorst, L. Schipper, U. Dittmer [5] They have determined the exposure of SARS CoV-2 to UV light and the results have shown that the virus is at high risk of ultraviolet light. An anti-bacterial cell that is completely inactive is UVC irradiation after nine minutes of exposure. The level of UVC required for complete inactivity was 1,048 mJ/cm2 and UVA exposure showed only a weak effect on viral inactivity for more than 15 minutes.

[24] M. Guettari, Gharbi, S. Hamza [6] They have developed a robot called i-Robot UVC which is fitted with eight UVC lamps around a central column and two lamps on the top. The column is fixed on a mobile base where several sensors are integrated to measure temperature, humidity and to detect motion plus position. The robot can assess automatically the disinfection time while monitored by a Wi-Fi connection from a phone.

3. Methodology

1) Arduino Mega in the robot functions as a Central Control Unit for the Robot
   Connected Peripherals:
   a) NodeMCU ESP8266
   b) L298N Motor Driver Module
   c) Ultrasonic Sensors
   d) Relay

2) Relay-based switching for switching UVC tube lights ON/OFF using the app joystick.
3) BLYNK mobile application used as joystick interface
4) SMPS alternatively lead-acid battery backup used as the power source to the robot.
5) A 360-degree rotating camera used to monitor the motion of the robot on-site
6) 06 units of 30W and 02 units of detachable 15W Low-Pressure Mercury UV-C tube lights used as disinfection luminaries of UV-PAUS Robot.

3.1 Block Diagram

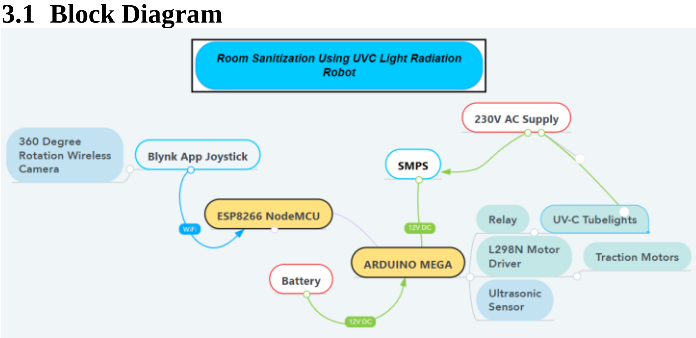

Figure 3: Block diagram

Fig 3. Illustrates the block diagram of the system.

The Arduino Mega 2560 microcontroller functions as the central unit of the robot receiving inputs from the Blynk Mobile application joystick through ESP8266 NodeMCU. The UV-C luminary supply is switched ON/OFF using the relay controlled by the inputs received to Arduino Mega from the joystick.

The traction motors of the robot are remotely controlled by Arduino Mega interfaced to L298N motor driver modules.

Traction motors, Arduino Mega, and NodeMCU ESP8266 are powered either by SMPS (Switched Mode Power Supply) or a Lead-Acid battery.

The supply source is switched using a Double Pole Double Throw (DPDT) switch.

Battery backup to the circuitry along with a unique 3-Part design enables complete ease in Wireless mobility and makes the robot travel-friendly and portable.

Battery Charging Level Indicator provided for real-time display of battery charging level statistics.

06 units of 30W UV-C tube light serve the purpose of complete 360 Degree sanitization at working plane level while 02 units of 15W UV-C tube light serve the unique purpose of 'Shadow Area Coverage' by UV-PAUS.

The 2 units of 15W UV-C tube light are detachable from the main body of the robot with a radial range of up to 4 meters.

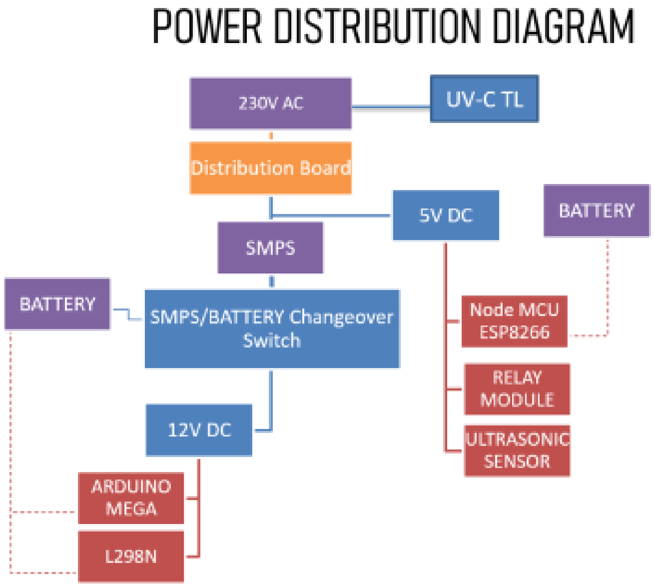

Figure 6.4: Power Distribution Diagram of UV-PAUS

3.2 How UV-C disinfects?

The germicidal action of UV-C takes place when wavelengths of 200 nm to 300nm hit the DNA structure of the pathogen or virus and is absorbed by the nucleic acid. Within this range, the 254nm wavelength of UVC is absorbed by the DNA and RNA of viruses. The acidic forces lead to the formation of glitter between pyrimidine residues in nucleic acid fibers leading to errors including pyrimidine dimers. These supplements can prevent recurrence or can prevent the expression of essential proteins, leading to death or physical activity[14,15]. Fig 4. gives a graphical representation of the above-mentioned process.

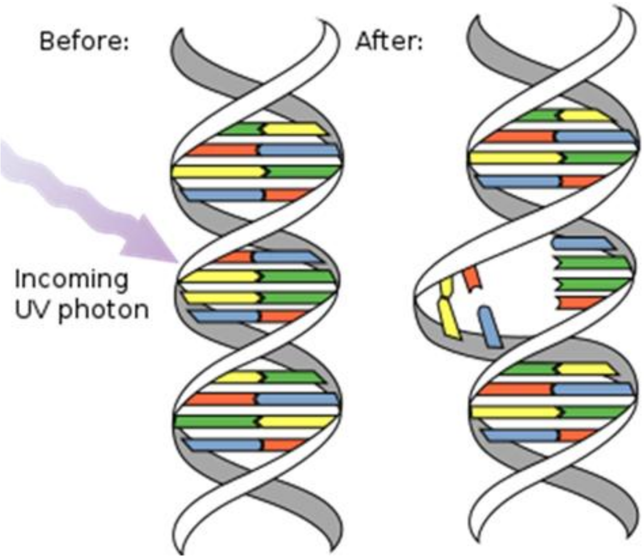

Figure 4

3.3 Effectiveness OF UV-C

The effectiveness of germicidal UV depends on
a) The length of time a microorganism is exposed to UV,
b) The intensity and wavelength of the UV radiation,
c) The presence of particles that can protect the microorganisms from UV,
d) A microorganism's ability to withstand UV during its exposure.
- The formation of dust layers on lamps can lower the output of the lamp, so the bulbs require frequent cleaning to ensure effectiveness.
- Cooling of the lamp under the airflow can also lower the output.
- Reflective material should be used to increase the efficiency of the light. Aluminum can be used as a reflector which is a more reflective material compared to others.
- The inactivation of germs depends on the dosage applied. The dosage is the product of light intensity and time which can be achieved by varying the time of exposure.

e) UV-C luminary selection and calculations.

For the Main luminary, we chose 6 x 30W and secondary 2 x 15W TUV T8 low-pressure mercury-based germicidal lamps mainly because the requirement was met by the luminary[16]
Dosage Calculations[17,18].

- UV dose=UV-C energy /Area
- And UV energy= UV radiation of luminary(W) x Exposure time(secs)
- Area= 4π(distance from bulb)² (considering spherical area to cover)
- Therefore,
- UV dose=$UV\ radiation\ of\ bulb(watts)*exposure\ time(secs)$ / $4\pi(distance\ from\ bulb)^2$
- Dose=__ Wsec/cm²
  And 1 watt =1000mj/cm²

For 30W tubes each tube with UV radiation 12W, the dosage will be as follows in mJ/cm². Table 2. depicts the theoretically calculated dosage.

Table 2

Meters \ Minutes	10	15	20
1	57.295	85.943	114.254
2	14.32	21.485	28.64
3	6.36	9.549	12.73
4	3.58	5.371	7.61
5	2.29	3.437	4.58

For 15 watt and UV radiation at 4.9W, the dosage will be as follows in mJ/cm². Table 3 shows the theoretically calculated dosages of the robot.

Table 3

Distance \ Minutes	1	5	10	15
10cm	233.95	1169.78	2339.58	3509.36
50cm	58.48	292.44	93.583	140.373
1 meter	2.33	11.69	23.34	35.09
2 meters	0.584	2.92	5.84	8.773

3.4 Designing of the robot

The robot majorly consists of 6 primary luminaries and 2 secondary luminaries, which performs the job of “Shadow area disinfection” which is unique in UV-PAUS. A treated aluminum sheet used as reflective material with 60%-89% reflectance of UV radiation [16] is used as a reflector for the luminary. Fig 5. shows a rough 3D design of the robot.

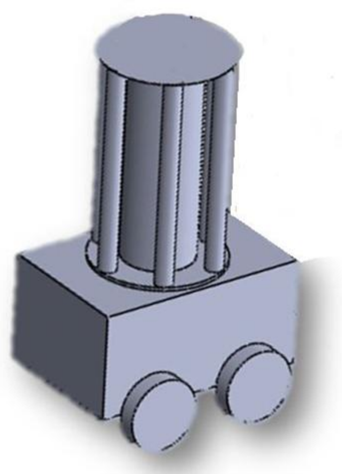

Figure 5: 3D rough diagram of the robot with 6primary luminaries

3.5 The developed Minimum Viable Product (MVP) UV-PAUS Robot

Figure 6.1: UV-PAUS Robot side profile image (on-site)

Figure 6.2: The Blynk Mobile Application wireless remote-control interface of UV-PAUS Robot with LIVE streaming

Figure 6.3: UV-PAUS Robot during Sanitization

4. Conclusion

The paper concludes with the completion of a developed minimum viable product robot with the name UV-PAUS. The UV-PAUS Robot exhibits multiple features like

Complete 360-degree Surface sanitization with ‘Shadow Area Coverage’
Remote wireless monitoring and operation of the robot
Portable and travel-friendly compact design

Which enables, increased personnel safety during sanitization of biologically contaminated site, Total effective and complete sanitization of the infected site without any residues.

The future developments include variants of design and increased effectiveness with reduced time requirement for sanitization along with a futuristic design of a Robotic Arm to the main body of UV-PAUS enabling increased ‘reach’ of the lights and effective dosage by the luminaries throughout the site planes.

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