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Study on the effectiveness of the sanitization activity of a robot equipped with UV lamps

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Abstract

The increasing focus on the health of individuals has forced a strong acceleration on research and development of new technologies to abate the microbiological component. The pandemic generated by the spread of the SARS-CoV-2 virus has imparted an even greater impetus in this direction. In large and busy environments, it is essential to implement existing air purification and surface cleaning techniques, to reduce the concentrations of microorganisms present as much as possible: for the abatement of airborne bacterial loads, physical methods (e.g., HEPA filters) are used, while, for surfaces, chemicals of different compositions (detergents and bactericides) are often used. The use of ultraviolet radiation is proving to be a very viable alternative for this purpose. The use of UV lamps coupled with automated systems allow constant service to prevent the spread of microbiological populations. The study reported here aims to verify the features of the bactericidal action produced by the ARIS-K2 robot. This specific machine is equipped with 6 UV-C mercury lamps, which emit electromagnetic radiation at a wavelength value of 253.7 nm. Ultraviolet light is divided into three categories, depending on the wavelength: UV-A (315-400 nm), UV-B (280-315 nm) and UV-C (100-280 nm). UV-C radiation is demonstrated to have the greatest microbicidal effect. The conducted study analyzes the survival of bacterial populations distributed on surfaces at varying distances from the robot and in the presence of obstacles. The results were also analyzed considering the dose-exposure time relationship to which the colonies were subjected.

Keywords: Biotechnology; Sanitation; Robot; Microbiology; UV-C; Treatments

1 Introduction

The SARS-CoV-2 pandemic has highlighted the ease and danger of pathogen transmission through simple air inhalation and direct contact with contaminated surfaces [1-2-3]. Increasing attention is given to all activities that may reduce the chance of an individual coming into contact with these pathogens. Disinfection is one of the most widely used techniques and is performed by physical or chemical methods. The insistent use of chemicals for sanitization, however, could lead to the development of resistance by pathogens, making the technique no longer effective and usable [4-5]. Physical methods for air treatment, such as the use of HEPA filters, require frequent maintenance, and can hardly be applied to small surface areas. Much application research has demonstrated the effectiveness of using ultraviolet radiation as a bactericidal agent [6-7-8]. UV rays can be divided into three categories, depending on the wavelength: UV-A (315-400 nm), UV-B (280-315 nm) and UV-C (100-280 nm). The greatest biocidal activity is implemented by UV-C: this specific radiation is absorbed by the bases of RNA and DNA. UV-C radiation, especially in the wavelength of 254 nm, induces a cross-linking between pyrimidine bases (thymine and cytosine) present on the same strand of DNA [9-10], making them

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unavailable for a physiological bond with the other strand. In DNA, the most common product of the action of ultraviolet radiation, are cyclobutyl pyrimidine dimers (CPD). These products block DNA translation, replication and transcription. The ability of UV to neutralize bacteria, viruses and fungi depends a lot, not only on the length of the radiation, but also on the time and distance of exposure [11]. There are low-pressure UV lamps that can produce a radiation with a second emission peak at a wavelength of 185 nm; the latter is able to interact with the oxygen present in the air and generate ozone (O_3) [12]. For this reason, many lamps are produced in quartz or synthetic materials, to absorb this unwanted emission. In recent years, the use of UV LEDs [13] is spreading, devices that allow light to be emitted at different ultraviolet wavelengths (265 nm, 280 nm). Compared to classic UV-C lamps, LED-UV does not contain mercury, resulting in reduced environmental impact and, from the point of view of effectiveness, some studies have shown an equal effect compared to traditional lamps [13-14-15]. The use of UV lamps with sanitizing action has numerous advantages: the possibility of allocating the lamps on mobile automated systems, no modification is necessary to the ventilation of the room, does not produce residues after treatment, guarantees a wide spectrum of action and rapid exposure times. The possibility of equipping robots with UV lamps is particularly interesting. This work tests the ability of the ARIS-K2 robot to sanitize the surfaces of a classic workplace. The activity of this type of robot is strongly influenced by the surrounding environment, for this reason two rooms have been selected as representative as possible. To obtain complete data, the following were evaluated: exposure time, source-target distance and influence given by the presence of any hurdles. Verifying the effectiveness of use in conditions of a robot equipped with UV-C lamps is the goal of this work. Effect checks are instead conducted both on a pure strain and on a bacterial suspension of ubiquitous environmental microorganisms. The choice of the target population was made trying to simulate as much as possible a natural contamination. The target areas are represented by heterogeneous areas and the assessment of the degree of abatement is derived from the comparison between the concentration of the microorganism before treatment and after. The germicidal or bactericidal action is closely related to the dose of energy produced (UV dose).

2 Material and methods

The goal of the experimentation is to define the bactericidal efficacy of robots equipped with UV lamps. The robot tested throughout the experimental phase is 'ARIS-K2' (YOUIBOT, Golden Apple Innovation Park, Ganli 2nd Road, Longgang District, Shenzhen). It is equipped with 6 mercury lamps (Philips TUV30W G30T8) that can generate UV radiation with a wavelength of 253.7 nm (UV-C). The accumulated light intensity is defined to be equal to 270 μW/cm^2. UV power is stated to be 180 W. The remote guidance system was developed by the Polytechnic University of Turin. The robot was tested in two different rooms: the first (Fig. 1A) is a rectangular teleconference room with a size of 140 m^3, while the second (fig. 1C) is a rectangular meeting room with a size of 70 m^3. To measure the dose of UV radiation to which the samples are subjected, '254 Quick Check' sensors were used (Intellego Technologies, Gustav III:s Boulevard 34, 4tr 169 73 Solna, Sweden). They provide positive feedback after the UV dose exceeds 6 mJ/cm^2. For dose values higher than 25 mJ/cm^2, 'UV-C 254 Dots' (Intellego Technologies, Gustav III) were used, which have a limit of 100 mJ/cm^2. The possibility of programming the movements of the robot allowed to carry out different tests. The '254 Quick Check' and 'UVC 254 Dots' sensors were arranged in the teleconference room, according to the diagram represented in figure 4A, at the points defined D1, D2, D3, X1, X2, X3 and X4, respectively at a distance of 1, 1.37, 1.74, 4.2, 3.8, 3.8, 3.8 and 3.6 m from the robot that is stationary in the center of the room. The exposure of the sensors was 60, 300, 600 and 900 seconds. For each period of exposure, multiple replicas were made. To assess the impact of the robot's movement on the UV dose, ARIS-K2 was made to move along a straight path perpendicular to the sampling point, as described by the red dotted arrows in Figure 1B. In this case, D1 and D2 are defined as sampling points. The robot's speed was set to 0.3 m/s in a first test, then to 0.5 m/s in another experimental phase. In this case as well, accurate exposure times were used: 300, 600 and 900 seconds. For each exposure period, 2 replicas (R1 and R2) were conducted. In the meeting room (Fig. 1C-1D) the ARIS-K2 was programmed to spin around the table at a speed of 0.1 m/s. The dosimeters were arranged according to points P1, P2, P3 and P4 (Fig. 1C). In the experimental phase, microbial populations representative of those most commonly found in this type of environment were used. To define the actual biocidal activity, bacterial populations were prepared at known concentrations to be exposed to ultraviolet radiation. Microbiological presence on surface was evaluated using the SRK hygiene monitoring kit (Copan Italy S.p.A.) considering a surface of 100 cm^2.

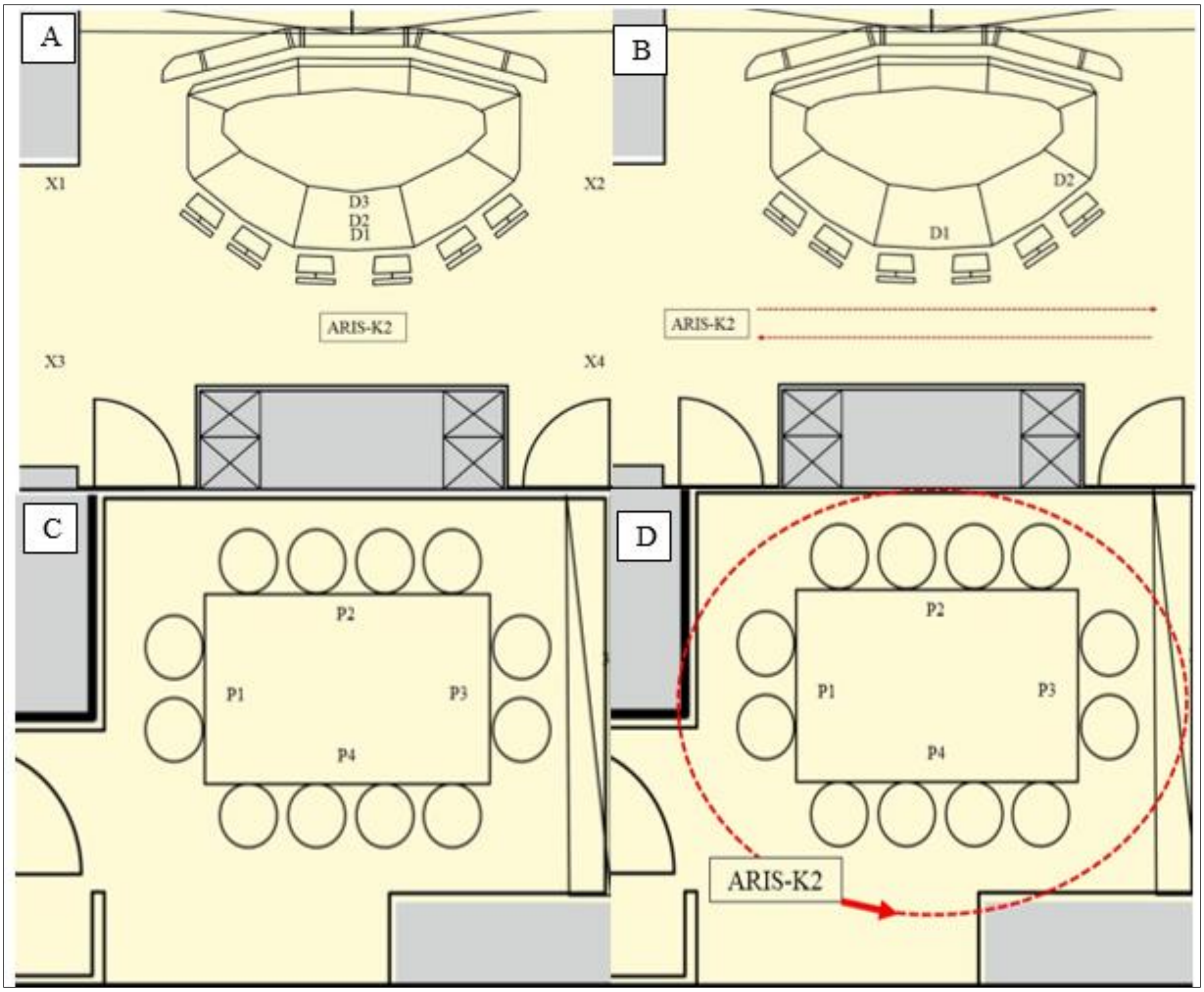

Figure 1 Floor plans of the two rooms in which ARIS-K2 was tested. Room A is the teleconferencing room and room C is the meeting room. In both cases, the moving robot (B-D) was tested

3 Results

3.1 Determination of the UV radiation dose

The first test was conducted inside the conference room, keeping the robot motionless. The highest radiation dose was measured at the D1 position after an exposure period of 900 seconds (Tab. 1). From the data collected it is possible to determine that the exposure time is a fundamental factor: in a minute of switching on the lamps, a response from the sensors was not measured. The angle of arrangement of the sensors, on the contrary, does not seem to affect the radiation dose. Subsequently, to evaluate the impact of the robot's movement on the UV dose, it was moved along a straight path perpendicular to the sampling point (Fig. 4B). The robot's speed was set to 0.3 m/s in a first test, then to 0.5 m/s in another experimental phase. The results summarized in Table 2 demonstrate how the movement of the machine affects the amount of UV rays that accumulates on the sensors. In the meeting room (figure 4D) the robot was programmed to move around the table at a speed of 0.1 m/s. Three tests were carried out, one with the chairs positioned around the table, the second with the chairs arranged to generate as little shade as possible on the table and one without chairs around the table. These were called respectively: TEST 1, TEST 2 AND TEST 3. Also, in this case the dose of radiation that hits the sensors is on average lower than that perceived with the immobile robot.

Table 1 Values of the dose (mJ/cm2) recorded at the various sampling points in room 1A

	Distance from source												
	D1			**D2**			**D3**			**X1**	**X2**	**X3**	**X4**
	1 m			**1.37 m**			**1.74 m**			**4.2 m**	**3.8 m**	**3.8 m**	**3.6 m**
	R1	**R2**	**R3**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**	**R1**	**R1**	**R1**	**R1**
Exposure time (sec)													
60		6	6		6	6		6	6				
300	6	25	15	6	15	6	6	6	6	6	6	6	6
600	25	25	15	15	25	15	15	15	15	15	15	15	15
900	50	50	25	25	25	25	25	25	15	25	25	25	25

Table 2 Values of the dose (mJ/cm^2) recorded at the various sampling points (D1-D2) in room 1A with robot in motion

		D1		**D2**	
		R1	**R2**	**R1**	**R2**
Speed (m/s)	Exposure time (sec)				
0.3	300	6	6	6	6
	600	25	25	6	6
	900	25	25	6	6
0.5	300	6	6	6	6
	600	25	25	6	6
	900	25	25	6	6

Table 3 Values of the dose (mJ/cm^2) recorded at the various sampling points (P1-P2-P3-P4) in room 1C without any obstacle

	Test 1				**Test 2**				**Test 3**			
	P1	P2	P3	P4	P1	P2	P3	P4	P1	P2	P3	P4
Dose (mJ/cm2)	25	25	25	25	25	25	25	25	25	25	25	25

3.2 Determination of the biocidal effect of the immobile robot

A first evaluation of the effectiveness of the robot was conducted on cultures of Escherichia coli at known concentration: 100 µL of a solution with known concentration (MPN 1553.1/100 mL) were plated on solid ground Tryptic Soy Agar (Biolife Italiana srl, Viale Monza, 272 - 20128 Milan). In this case the robot was kept motionless. The plates were placed at points D1, D2, D3, X1, X2, X3 and X4 in the teleconference room. The exposure time of the UV plates was 300, 600 and 900 seconds. The samples were then incubated for 24 hours after sampling at 36 °C. The results are shown in the table 4. The table 5 summarizes the results obtained by contaminating the same points (D1-D2-D3) of the previous experiment with ubiquitous natural microorganisms. The initial concentration was not known, which is why control whites were set up. The sampling location was limited to 100 dm^2 and samples were obtained by surface infill.

Table 4 Count the colonies grown on the agar plates because of UV treatment

	D1	D2	D3	X1	X2	X3	X4	BLANK
	1 m	**1.37 m**	**1.74 m**	**4.2 m**	**3.8 m**	**3.8 m**	**3.6 m**	
Exposure time (sec)								
300	0*	3*	22*	0*	2*	3*	0*	>300
600	0*	1*	2*	1*	0*	0*	0*	>300
900	0*	0*	2*	2*	1*	1*	0*	>300

*Unquantifiable bacterial growth on the edge of the plate facing the robot

Table 5 Colonies grown on plates obtained by buffering a contaminated surface with a sample containing ubiquitous microorganisms. The results are expressed in ufc/dm^2

	D1	D2	D3	BLANK
EXPOSURE TIME (sec)	1 m	1.37 m	1.74 m	
60	138	123	247	679
300	59	85	130	958
600	14	68	98	483
900	23	22	36	538

3.3 Determination of the biocidal effect of the moving robot

In the teleconference room (Fig. 1B), the sanitizing effect of the moving robot was tested on surfaces D1 that were first naturally contaminated and then artificially contaminated. Surface samples, after the exposition, were taken by pad considering a surface of 100 cm^2 (Tab. 6-7). A test to verify the effect of a footprint generated by chairs placed around a table was conducted in the meeting room. First the experimentation with chairs was carried out and then without (Tab. 8). Sampling was carried out at points P2 and P3 in the meeting room (Fig. 4C). The table 5 summarizes the results obtained by contaminating the same points (D1-D2-D3) of the previous experiment with ubiquitous natural microorganisms. The initial concentration was not known, which is why control whites were set up.

Table 6 Sanitizing effect of the moving robot on the D1 sampling point. The results are expressed in ufc/dm^2

	D1 artificially contaminated	D1 naturally contaminated	Exposure Time (sec)
SPEED			
0.3 m/s	1.4 E+05	<10	300
	300	<10	600
	80	200	900
0.5 m/s	3.32 E+06	<10	300
	3.0 E+05	<10	600
	6.6 E+05	<10	900
	8.2 E+06	200	0

Table 7 Sanitizing effect of the moving robot on the D2 sampling point. The results are expressed in ufc/dm^2

	D2 artificially contaminated	D2 naturally contaminated	Exposure Time (sec)
Speed (m/s)			
0,3	4.7 E+05	10	300
	1 E+04	10	600
	40	30	900
0,5	2.11 E+06	10	300
	9.7 E+05	10	600
	3 E+05	<10	900
	1.3 E+07	30	0

Table 8 Difference between obstacle and obstacle treatment. The results are expressed in ufc/dm^2

	P2	P3
Chairs present	1.9 E+03	1.1 E+02
Absent chairs	1.4 E+02	1.0 E+02

4 Discussion

It can therefore be concluded that the use of UV-C lamps, in collaboration with automated systems, can represent a useful tool in environmental disinfection, to be interpreted as valid to be added to the standard cleaning and disinfection protocols. The environmental impact should not be overlooked, since the most used lamps are those with mercury vapors, which represents a special waste and as such must be disposed of. The tests conducted have made it possible to confirm the already known effectiveness of a bactericidal treatment using UV-C lamps. This effect was noted, in this specific study, to be strictly dependent on the time of exposure, which affects the radiation dose to which microorganisms are subjected: the higher the dose, the greater the desired effect will be. The robot has proven to be able to move autonomously, even in tight environments, producing a bactericidal effect on both horizontal and vertical surfaces. A lower biocidal effect has been found in the presence of obstacles capable of generating shadow areas that shield the ultraviolet radiation produced by ARIS-K2. This effect is amplified for horizontal surfaces. Based on the data collected, it can be said that the use of the robot would be optimal in places with a reduced presence of obstacles and with vertical surfaces. For an efficient use, an adequate mapping of the place to be treated is suggested, to identify the critical issues that could prevent ARIS-K2 from fulfilling its task, also it will be necessary to draw a path able to guarantee a sufficient dose of radiation on all the surfaces to be treated.

It is not yet believed that Aris K2 can replace the efficiency of anthropic intervention, which is able to evaluate and intervene independently. However, it can effectively support the traditional sanitization activities by following the guidelines that emerged from our research. At the same time, we believe that the technological evolution of the near future will support the resolution of the attention points that have emerged during our activity, and this will lead to increasingly effective autonomous solutions for surface sanitization.

5 Conclusion

This study demonstrated the potential effectiveness of using automated systems equipped with UV lamps for sanitizing offices. It was shown that the bactericidal efficacy is closely dependent on the time of exposure to UV light, the radiation dose received and the angle of incidence of the radiation and light. This type of technology will allow a reduction in the use of chemical bactericidal compounds, reducing the evolution of resistance to these compounds.

Compliance with ethical standards

Disclosure of conflict of interest

No conflicts of interest to disclosed.

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