Study of UV-C Intensity Distribution Using the TIAMO-C6 Sensor

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Abstract* – This paper presents a measurement application designed to evaluate ultraviolet-C (UV-C) intensity generated by commercially available lamps. Our work was done in the context of proliferation of different devices and technologies deployed with the purpose of virus (especially SARS-CoV-2) and bacteria inactivation. The proposed system is based on the UV-Tiamo-C6 sensor module, a professional device designed for purification lamp control. The intensity characteristics for two types of lamps (25W and 36W) were investigated in relation with the distance from the source. Furthermore, the 2D space distribution of the intensity was analysed by means of a customized mobile platform built on an iDrive Rock Climber vehicle. Other facilities of the proposed measurement experiment include live video transmission, automated data saving/analysis and remote control. Functionality tests performed in the laboratory confirm that the proposed system was properly designed and implemented. As future development, we will focus on correlating the effectiveness of a disinfection device, based on such UV-C lamps, in relation with exposure time, distance and target colonies type.
Keywords: ***ultraviolet-C, disinfection, measure, irradiation, TIAMO-C6***

I. INTRODUCTION

Ultraviolet radiation exists everywhere around us in our life. It is part pf the electromagnetic spectrum with a wavelength ranging from 10nm to 400nm [1]. The wavelength range in UV disinfection that we are going to work on is 220-280nm (UV-C), specifically 253.7nm, bacteria having the highest light absorbance from 250nm to 265nm. Biological effects in human's overexposure to UV-C radiation varies with wavelength, photon energy and duration of exposure [2]. UV-C is classified as probable human carcinogen by the US National Toxicology Program with various consequences depending on exposure time, ranging from mild rashes especially in the eye region and in some cases may even lead to skin cancer.

We aim to demonstrate UV-C radiation losses and efficiency over various distances without human interaction. The proposed platform shall move in the desired area, identify and measure the 253.7nm radiation, if any, produced by various sources. The platform is remote-controlled from a safe distance and can measure the intensity of a single point in a short period of time or produce a 2D matrix representing the UV-C radiation over a longer period of time.
Ultraviolet disinfection is one method of the disinfection that has been widely used in equipment sterilization using germicidal UV-C ($254nm$).

Following we'll introduce a robotic platform that can be remotely operated and sent into an area with presence of ultraviolet radiations without the operator needing to expose himself to said radiations and can detect and measure light radiations of type UV-C.

II. MOTIVATION OF WORK

Ultraviolet (UV) irradiation, due to the germicidal properties, is a widely used and effective noncontact method for inactivating viral pathogens. In many applications, such as ground, surface, or water sterilization, it is accepted as an attractive and cost-effective means for pathogens control. Over the last decade, but specially in the context of the SARS-CoV-2 pandemic, numerous types of UV generating devices have been developed and are commercially available. These "no-touch" technologies, like aerosol and vaporized hydrogen peroxide spreading devices, UV emitting devices, pulsed-xenon UV light systems etc., have proven to be capable to reduce bacterial contamination. However, continued efforts to improve manual decontamination methods are justified. Research activities analyzing the efficiency of modern technologies used to supplement traditional cleaning and disinfection methods, have become increasingly popular [3-5].

III. ROBOT PLATFORM

We proposed a robotic moving platform with four individual motors, each controlling one single wheel. In Figure 1, the modified measurement vehicle, including the platform, is presented. The system is managed by a Raspberry Pi 4 (RP4) development board. This board controls the platform movements, provides video streaming, and computes real time results. An Arduino

Nano (AN) board, with a 10-bit ADC, is used to sample the UV-TIAMO-C6 output. The AN is also responsible for driving the vehicle servo motors by means of two L298N dual full-bridge drivers. Each driver is capable of bi-directionally control of two sets of motors of up to 50V@3A each, powered directly from the platform's battery pack. The motor control is done by the RP4. The vehicle has special wheels that do not require steering the front or back, like a conventional RC car. The wheels feature a double-cylinder structure made of hard rubber that can freely move around and is placed at a 45° angle with respect to the drive train. The system can also be operated through an ESP32 module, specifically an ESP32-CAM with minor adjustments. The ESP32 can provide video feed at a lower resolution (1280x1024 vs 3280x2464 of RP4 camera) and it needs to have internet connectivity. From a software perspective, the system uses a multitude of libraries. The Python Server is an example. Other examples are the PiCamera Python library for the video streaming server, the GPIOZERO library used for controlling the L298N motor drivers, the ESP32 Camera Driver library for controlling the ESP32 and the Processing Software on the RP4, for generating the matrix images.

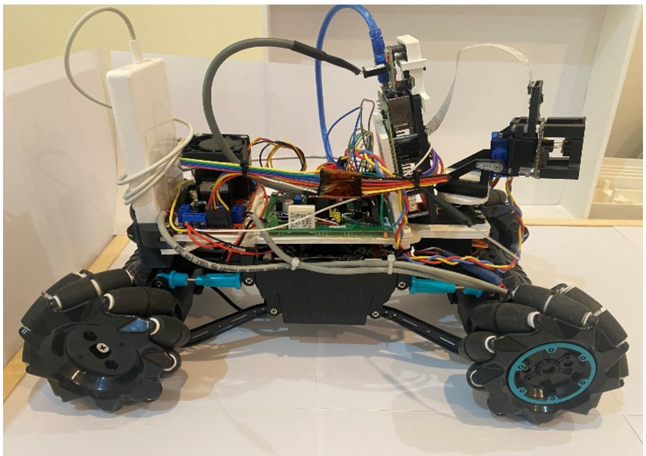

Figure 1. Measurement vehicle platform

A. Platform Movement

The platform is able to move in all directions, forward/backward, left/right but also diagonally with the ability to rotate in place as shown in Figure 2. This configuration was chosen in order to allow the platform to be easily moved inside different rooms and overcome and avoid obstacles.

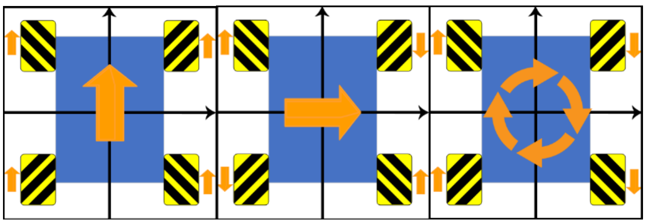

Figure 2. Platform Directional Movement

B. Head Movement

The sensor that we are using together with a video camera is attached to the platform's head as shown in Figure 3. The head is made up of two servomotors in order to give the head 2-directional movement (up/down, left/right). This configuration allows for the user to individually control the camera mounted on the moving head without moving the actual platform and allows for a 2-dimensional matrix to be produced.

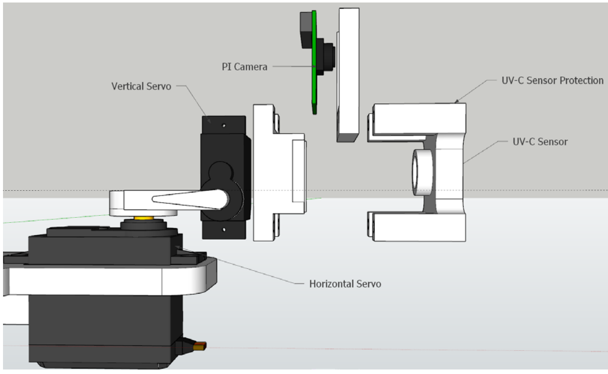

Figure 3. Platform Moving Head

IV. SENSOR

The sensor we are using to measure light irradiation is the UV-TIAMO-C6 which is a UV-C only amplified SiC UV detector. It operates in the range of 225-287nm with a max irradiance of $1.8mW/cm^2$ @ $254nm$. From [6] we can see in Figure 4. the spectral responsivity of the sensor. It can be noted that the sensor is most efficient at 275nm wavelength.

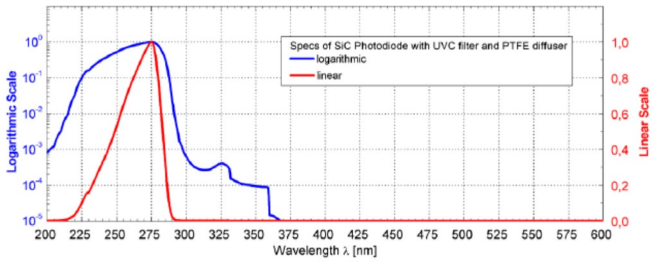

Figure 4. UV-TIAMO-C6 Normalized Spectral Responsivity

The UV-C detector is able to read one sample every 69 milliseconds.

V. TEST DATA AND RESULTS

The proposed system was tested in an UV-C exposed space at the University Politehnica Timişoara, without human presence. For experimental purposes it facilitates live video transmission and automated data saving/analysis.

For each test we are taking a number of 5600 readings with the UV-C detector, even for fixed-point reading. This way we are able to see the evolution, if any, of the 253.7nm wavelength light. Each measurement takes 0.07 seconds giving a total of 392 seconds for 5600 readings.

A. Single Point Measurements

In single point mode, measurements are taken from a single point without moving the head. The number of measurements is the same as in the 2D matrix measurement mode for consistency.

As a baseline for our tests and in order to make sure everything works correctly, multiple tests were conducted from a distance of 1 meter with one and two UV-C lamps.

A comparative evaluation of the 1x36W lamp and 2x36W lamps are shown in Figure 5.a for one lamp and Figure 5.b for two lamps, from 1 meter distance at an angle of 90° between the sensor and the UV light. At the start of the acquisition process the UV-C sources are turned off. After approximately 10s, the UV-C sources are activated. Note the sudden rise in the sensor module response, then an evolution towards values which settle to averages of approximately 329mV or 118 μW/cm^2 for one lamp and approximately 656mV or 236 μW/cm^2 for two lamps.

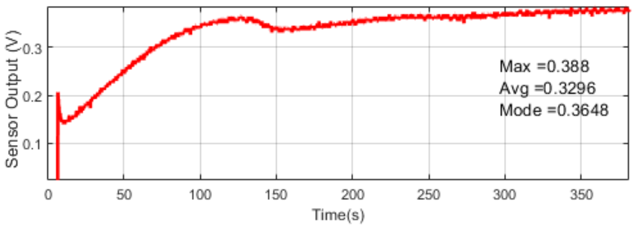

Figure 5.a 1x36W Lamp Results Evolution

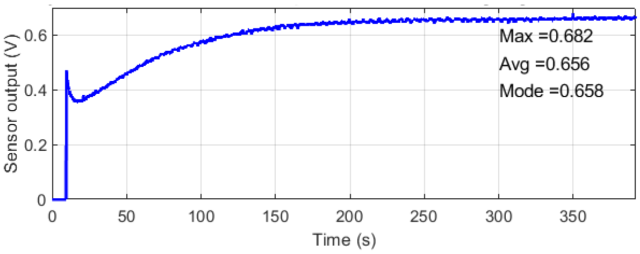

Figure 5.b 2x36W Lamps Results Evolution

The following values are recorded for the last 190s of exposure time. We have estimated that after approximately 200s, the irradiance levels remain in a constant regime. In Figure 6.a and Figure 6.b histogram evaluation of 1x36W lamp vs 2x36W lamps is shown.

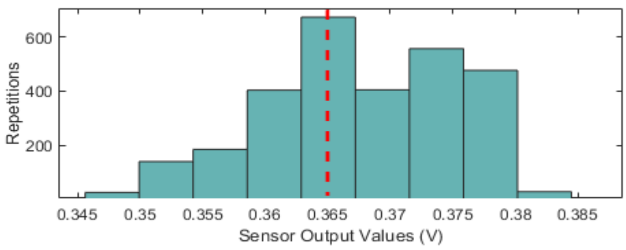

Figure 6.a 1x36W Lamp Histogram Evaluation

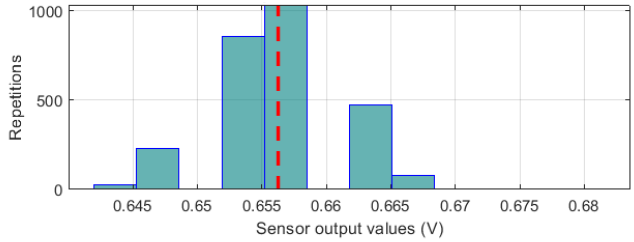

Figure 6.b 2x36W Lamps Histogram Evaluation

The average value is presented with red, interrupted line. By inspection, the dataset presents acceptable accuracy. If we consider that by increasing the number of recorded samples, the dataset presents a normal distribution, we can estimate the standard deviations as 2.7mV for a single 36W lamp and 4.7mV for two 36W lamps. Thus, after approximately 200s from the activation of the UV-C sources, resulting measurement values are tightly grouped, with steady repeatability characteristics.

After those sets of tests, we are confident the setup and the sensor work correctly. Following in Table 1 are shown the results from different distances to the UV lamp.
The calculated irradiance has been calculated using the Formula 1 taken from [7] where B is the width of the UV lamp, C is the distance between the sensor and the UV lamp and α is the angle formed between the middle of the lamp, the sensor and the margin of the lamp which is equal to half the width of the lamp (192.5mm).

$$E = \frac{\varphi}{2*\pi^2*B*C}(2\alpha + sin2\alpha) \qquad (1)$$

The expected irradiance is calculated taking a linear sensor irradiance from the max irradiance of the sensor of 1.8mV/μW @ 254nm at 5V.

Distance	Average [V]	Calculated Irradiance [μW/cm^2]	Expected Irradiance [μW/cm^2]
0.1m	4.987	1795	[saturation]
0.2m	4.86	1749	1815
0.3m	3.43	1234	979
0.4m	1.9	684	594
0.5m	1.234	444	396
0.6m	1.059	381	275
0.7m	0.78	280	198
0.8m	0.61	219	154
0.9m	0.488	175	121
1m	0.356	128	108

Table 1. Readings Results

In Figure 7, 2x36W lamps ensemble irradiance characteristics in relation with the measurement distance. The 0.2m dataset presents non-stable characteristics. The sensor module presents a maximum signal output at approximately 95% of the supply voltage. Assuming the supply voltage is ideal at 5V, the maximum accurate value returned by the C6 should be around 4.75V. Our dataset, at 0.2m, includes a peak of 4.89V. Thus, the consistency of this dataset must be evaluated. However, for evaluation purposes we can accept the average 4.67V. The other datasets present good stability since they have been recorded after the initial warm-up period of the UV-C source.

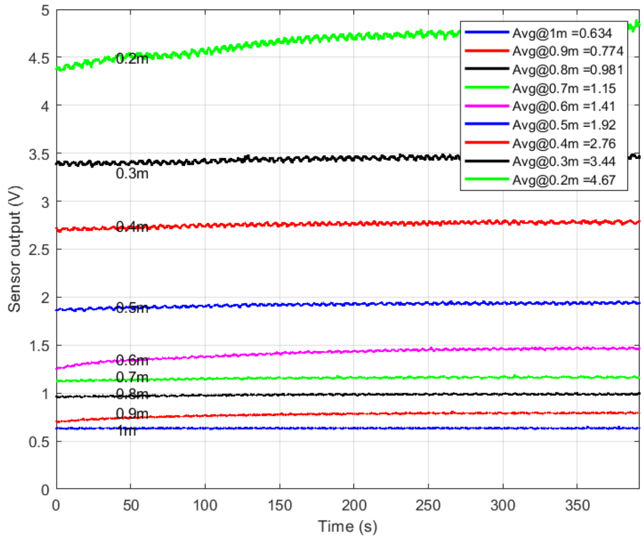

Figure 7. Intensity measurements – 2x36W lamps, distance tests

UV-C intensity characteristics depending on the distance with a 95% accuracy is shown in Figure 8. The results are consistent with the nominal ones presented in [8].

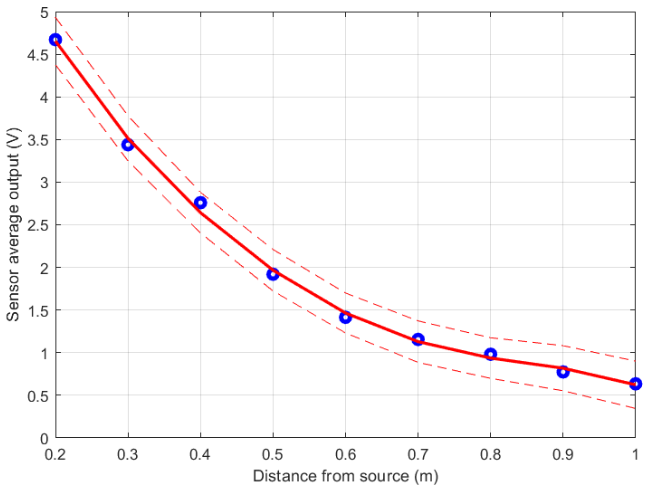

Figure 8. UV irradiance vs distance from lamps

B. 2D Matrix Measurement

In this scenario, we are moving both servo motors horizontally and vertically, starting from the upper left corner and traversing a grid-like pattern as shown in Figure 9. Each square point in the generated image represents a measurement with higher UV intensity being displayed brighter and lower UV intensity being darker. Each pixel is represented in increments of 32mV at a reference voltage of 3.3V and 48mV at a reference voltage of 5V. The corresponding voltage (0-5V or 0-3.3V) is translated into gray-scale values (0-255) in order to create the desired image. The number of different point scans and the resolution of the resulted image is equal to 100x56.

1	2	3	4	5	6	7	8	….	100
200	199	198	197	196	195	194	193	…	101
201	202	203	204	205	206	207	208	…	300
400	399	398	397	396	395	394	393	…	301
…	…	…	…	…	…	…	…	…	…
5501	5502	5503	5504	5505	5506	5507	5508	…	5600

Figure 9. 2D Matrix Traversal Path

C. Results

1. Probe 1: Single 25W UV-C source

In this test, a single generic UV-C light source as presented in Figure 10.a was used at a distance of 1.5m with a reference voltage of 3.3V, with the UV-C lamp in in middle, upper part of the image. The 2D results matrix can be seen in Figure 10.b and the UV-C outline can be seen in the center of the image.

Figure 10.a 25W Single Light Source

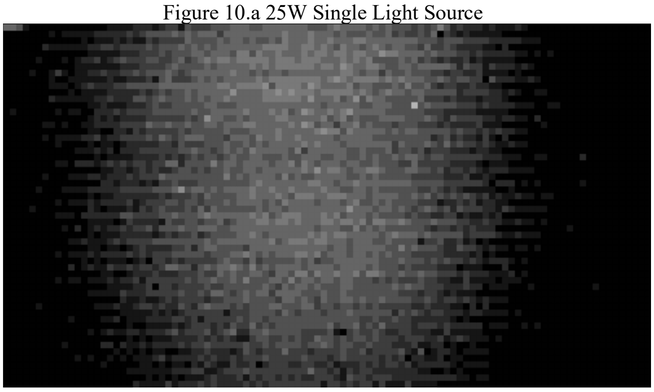

Figure 10.b 25W Source 2D Matrix Result

In this configuration we achieved an average value of 0.0096V, not counting the null values and a maximum of 0.0290V in the center of the UV blob equivalent to approximately 16μW/cm^2. As expected, the irradiation of the 25W lamp is much lower than the irradiation of the 36W lamp.

2. Probe 2: Double 36W UV-C source

In this test, we used two UV-C sources of 36W each from a distance of 1m as shown in Figure 11.a. Each UV lamp has an irradiance of 110μW/cm^2 at a distance of 1 meter.

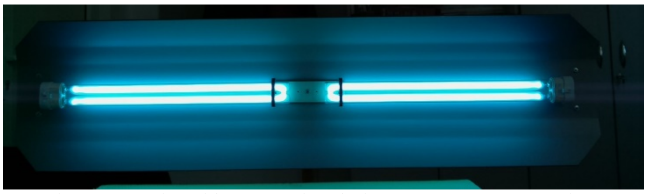

Figure 11.a Live video streaming during measurement operations

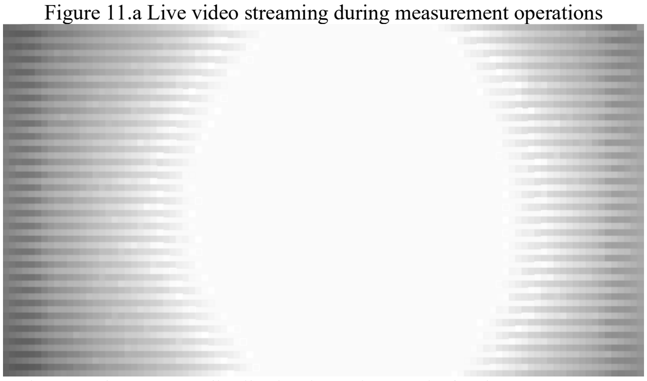

Figure 11.b 2D space distribution intensity matrix for the 2x36W UV-C lamps testing, at 0.5m distance.

In this configuration we achieved an average of 1.215V and a maximum of 1.93V equivalent to 705µW/cm^2 in the middle of the UV-C blobl. The UV light blob can be seen in the middle of the image.

CONCLUSIONS

In conclusion our tests were a success. We were able to measure in different scenarios with different lamps and from different distances, with values close to the ones presented in the datasheet of the lamps and the sensor. The tests were successfully done remotely through the remote controller without any human presence in the area where the tests were done and demonstrates the platform can be used for this type of tests.

ACKNOWLEDGMENTS

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