Towards the Development of Test Methods for Collaborative Cleaning with a UV Robot

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***Abstract*—The use of ultraviolet germicidal irradiation (UVGI) as a means of room sterilization in hospitals has been increasing in recent years. To protect staff and patients from exposure to potentially harmful UV rays, it has become standard practice to evacuate rooms prior to use. The aim of this work was to explore how a UV robot might be deployed safely alongside people. Doing so could potentially extend the number of settings where UV disinfection can be safely deployed as well as reduce the time taken to clean front-line healthcare facilities. For UV robots to operate with people in the room, it is required that appropriate personal protective equipment (PPE) is worn, the UV output of the device is regulated and tests are performed to verify that background radiation levels do not exceed occupational safety thresholds. In this paper, we outline three conditions that must be met for safe collaborative cleaning with a UV robot. In doing this, we provide a framework for performing a new type of robot-enabled room disinfection.**

I. Introduction

Room cleaning and disinfection procedures play a critical role in hospitals to limit the spread of healthcare associated infections (HCAIs). Traditional cleaning practices, where human cleaners manually administer chemical disinfectant to surfaces, are subject to many practical limitations including high susceptibility to human error [1]. UVGI has been shown to overcome many of these limitations and when used correctly, offers an effective complementary method of disinfection [2]–[4] .

UVGI devices may form part of a buildings fixed infrastructure or comprise mobile devices that can be transported between rooms. The latter category of devices are commonly referred to as ‘UV robots’. These devices emit UV light in the UVC spectrum (wavelengths 200-280nm) and may cause harm if directly exposed to skin and eyes in high doses. The legal daily exposure limit (over an 8 hour period) of unprotected skin and eyes in Europe, as per the EU Directive 2006/25/EC, is an effective radiant exposure value, H_{eff} of $30J/m^2$. For a UV-C light source, this can be calculated by the following equation:

$$H_{eff} = \Sigma_{\lambda=180nm}^{\lambda=400nm} E_\lambda \cdot S(\lambda) \cdot \Delta\lambda \cdot \Delta t \tag{1}$$

Where E_λ = spectral power density $(Wm^{-2}nm^{-1})$, $S(\lambda)$ = spectral weighting accounting for wavelength dependence of health effects of UV radiation on skin and eyes (dimensionless), $\Delta\lambda$ = bandwidth of measurement intervals (nm), and Δt = duration of exposure (s).

So long as these thresholds are not exceeded, a UV robot may operate alongside and in the vicinity of people.

II. Collaborative Cleaning with UV Robots

It is common for commercially available UV robots to irradiate omni-directionally and many use lamps that achieve near-range UV power values that instantly exceed occupational limits if exposed directly to human skin and eyes. To the best of our knowledge, manufacturers of all major commercial UV robot platforms that use designs like this stipulate that the product should not be used with people in the room with it.

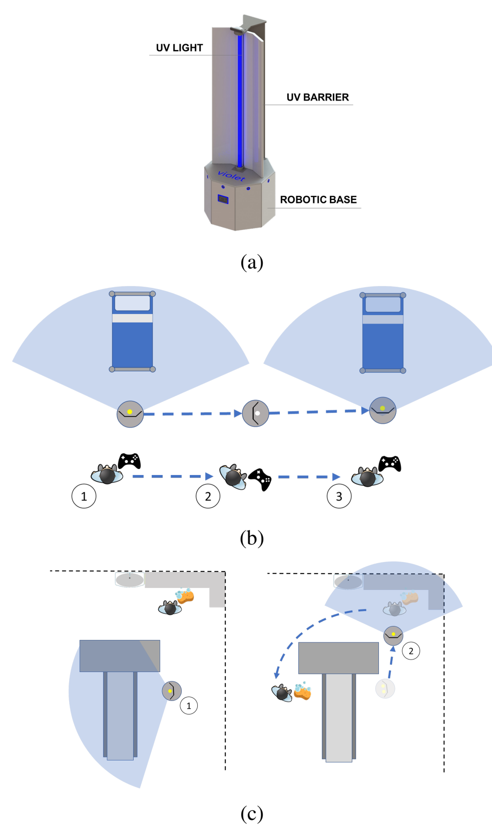


Fig. 1. Summary of collaborative cleaning process involving a UV robot; (a) schematic of a UV robot that can potentially be used in a collaborative cleaning scenario, (b) illustration of how a UV robot may be safely tele-operated by a human located in close proximity, (c) illustration of a collaborative cleaning process where the robot and cleaner work in coordination.

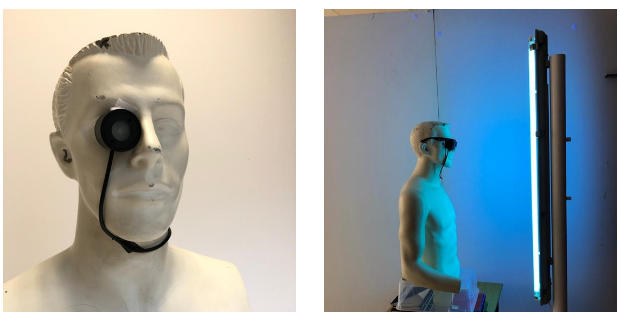
An alternative design, such as that of the *Violet* robot [5] (Fig. 1(a)), overcomes this issue by actively limiting its field of irradiation through the use of a UV blocking barrier. With a system like this, it’s conceivable that a person standing behind the robot may be able to tele-operate it while avoiding UV exposure (Fig. 1(b)). An alternative cleaning scenario is also envisioned, where the robot disinfects one area while a human worker performs cleaning-related tasks in another part of the room that is free from UV irradiation (Fig. 1(c)). This latter scenario is innately collaborative, requiring close coordination between the robot and the human cleaner.

III. Methods

To demonstrate a collaborative cleaning procedure involving a UV robots is safe, there must be evidence that PPE worn by the operator provides protection from UV irradiation, that accidental incidental exposure falls within occupational safety limits and that background UV irradiation levels are negligible.

A. Protective Personnel Equipment

By wearing appropriate PPE that covers exposed skin and eyes, a worker may be able to work alongside a UV robot for an indefinite period of time. Given that the transmittance of UVC irradiation is low and it is filtered by most common materials, it's possible that specialized PPE may not be required. To determine the resistivity of an item of clothing or PPE to UVC irradiation, a test can be performed that involves placing the material over a UVC sensor and then exposing it to a UVC light source (Fig. 2).



(a) (b)

Fig. 2. Testing the transmittance of goggles to UV irradiation. (a) UVC sensor installed on mannequin (b) Exposing the sensor and goggles to a UV light source.

B. Controlling UV Exposure

The potential for harm due to unintended or incidental exposure to UV irradiation from the robot can be mitigated significantly by reducing the UV power output of the robot and introducing standard operating procedures that ensures people cohabiting the room maintain a safe distance from the robot. Figure 3 demonstrates an implementation of this procedure. Background UVC irradiation levels for a UV robot cleaning procedure may be measured by distributing a cluster of UV sensors in the room and recording their values over the cleaning period.

C. Monitoring UV Exposure

Another way to ensure worker safety and monitor background radiation levels during a UV disinfection procedure is for people occupying the room to have UV sensors embedded in a wearable device (such as a face shield). These devices can track the ambient UV radiation levels in their vicinity, and can warn them if they exceed a defined threshold.

Fig. 3. Collaborative human-robot room cleaning; a cleaner wipes the machine while the robot irradiates a different part of the room with UVC light.

IV. Summary

New test methods are needed to establish the conditions necessary for humans to occupy rooms and work safely alongside UV robots. Meeting these requirements could extend the applicability of UVGI technology to parts of the hospital where it is seldom feasible to evacuate the room and could help shorten room turnover times, leading to an increased capacity of frontline services like radiology and operating theatre.

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References

[1] J.-H. Yang, U.-I. Wu, H.-M. Tai, and W.-H. Sheng, "Effectiveness of an ultraviolet-c disinfection system for reduction of healthcare-associated pathogens," *Journal of Microbiology, Immunology and Infection*, vol. 52, no. 3, pp. 487–493, 2019.

[2] A. Nagaraja, P. Visintainer, J. P. Haas, J. Menz, G. P. Wormser, and M. A. Montecalvo, "Clostridium difficile infections before and during use of ultraviolet disinfection," *American Journal of Infection Control*, vol. 43, no. 9, pp. 940–945, 2015.

[3] N. A. Napolitano, T. Mahapatra, and W. Tang, "The effectiveness of uv-c radiation for facility-wide environmental disinfection to reduce health care–acquired infections," *American journal of infection control*, vol. 43, no. 12, pp. 1342–1346, 2015.

[4] J. K. Schaffzin, A. W. Wilhite, Z. Li, D. Finney, A. L. Ankrum, and R. Moore, "Maximizing efficiency in a high occupancy setting to utilize ultraviolet disinfection for isolation rooms," *American journal of infection control*, vol. 48, no. 8, pp. 903–909, 2020.

[5] C. McGinn, R. Scott, N. Donnelly, K. L. Roberts, M. Bogue, C. Kiernan, and M. Beckett, "Exploring the applicability of robot-assisted uv disinfection in radiology," *Frontiers in Robotics and AI*, vol. 7, 2020.