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Surface-aware ultraviolet disinfection through a mobile manipulator

Andrea Borgese, Giorgio Grassi, Dario Calogero Guastella, Giuseppe Sutera, and Giovanni Muscato
Dipartimento di Ingegneria Elettrica Elettronica e Informatica
Università degli Studi di Catania, Catania, Italy, 95125
andrea.borgese@phd.unict.it, giorgio.grassi97@gmail.com, dario.guastella@dieei.unict.it,
giuseppe.sutera@unict.it, giovanni.muscato@unict.it

I. Introduction

A crucial requirement in combating COVID-19 pandemic is to minimize the probability of contagion in every place shared by several people, especially in confined indoor workplaces and in the hospitals. Current ordinary disinfection processes are carried out by human operators who employ cleansers and specific disinfectants. Ultraviolet germicidal irradiation (UVGI) is a disinfection technique that uses UV light to inactivate a pathogen. This process blocks the ability of a virus pathogen to replicate, by inducing the formation of covalent bonds in its nucleic acids, which leads to its mutation and makes it non-infectious. The optimal wavelength for the germicidal purpose is 254 nm which falls into the so-called UV-C band and is typically used in conventional disinfecting tool. However, UV-C light can harm human eyes and skin and the damage entity depends on the exposure duration and the intensity of the irradiation.

For this reason, a robotic solution can help to prevent the human operator from being accidentally exposed to the UV source, as well as to the potential presence of pathogens. To this end, we propose a mobile robotic manipulator, equipped with a UV source as an end effector. We aim to ensure an efficient yet complete UV irradiation of complex surfaces and objects inside buildings, by exploiting the dexterity given by the manipulator to properly move and orient the UV emitting source.

II. Related work

The COVID-19 pandemic has given a considerable momentum among the scientific community to robotic solutions for contrasting infectious diseases [1]. Several solutions based on contactless disinfection through UVGI have been proposed as well [2]. Some environmental disinfection processes with static omnidirectional UV lamps, either mounted on manually moved platforms [3] or on mobile robots [4], have been proposed. However, the main limitation of such solutions is related to the fixed emitting source that, albeit being on a mobile platform, often produces shadows, i.e. areas not directly reached by UV rays, thus reducing, or even nullifying, the disinfection efficacy [3], [5], [6].

To overcome this issue, a teleoperated mobile manipulator is proposed in [3]. The authors present a dosage mapping strategy to monitor the disinfected surfaces. Nevertheless, the manually teleoperated coverage strongly limits the efficiency of the disinfection procedure.

Another interesting solution is described in [5]. In this case a human supervisor drives the platform to an area for disinfection and identifies a region of interest (a planar surface) over which the system performs a 2D coverage path planning for the manipulator. However, the main limits of such a solution lie in both the fixed direction of the emitting source during the coverage and the discretized representation of the environment for the dosage assessment. The latter makes intractable the application of the solution to a full 3D open space.

III. Proposed solution

We propose a platform capable of performing the disinfection of indoor environments, integrating classical systems for UVGI on a mobile robotic manipulator and computing the scanning trajectories of the emitting source online, based on the visual information and the geometry of the area of interest acquired through an onboard RGBD camera.

The main contributions of our solution, with respect to those proposed in the literature, are 1) the surface-aware emitting source, which is moved and oriented by the robotic arm so that all the surfaces to be disinfected are reached, by eliminating dead zones and shadows while ensuring a perpendicular irradiation and 2) the proposed 3D coverage path planning.

A. Coverage path planning

UVGI effectiveness is considerably decreased in the case of non-direct exposure of the surfaces to UV light [3], [5]. To avoid this, we propose to adapt coverage path planning strategies [7] to the problem of UV surface scanning. We address the problem as a sequential coverage path planning of flat planar surfaces. We first decompose the point cloud of the environment acquired by the RGBD camera into a set of 2D flat surfaces, compute a back-and-forth coverage trajectory

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Fig. 1. The prototype of mobile manipulator developed for the testing.

for each of them and finally merge these trajectories through a backtracking policy. Taking into account the UVGI model described in [8] and the UV source's properties, a suitable coverage timing is considered to ensure the proper UV dosage for virus inactivation. The distance of the end effector to the surface is constantly monitored as well, still to ensure the proper UV exposure of the surface, by acting on the scanning velocity of the irradiation source.

B. Surface-aware disinfection

To further enhance the efficacy of UVGI, we take into account point cloud normals to derive end effector's orientation. In particular, UV light direction is kept perpendicular to the surface during the coverage, thus making the dosage prediction from the UVGI model closer to the real one [9].

IV. Experimental setup and results

The preliminary prototype developed for assessing the goodness of the proposed method is shown in Fig. 1. The mobile platform has two differential drive wheels and two balancing caster wheels and measures 120×70×45 cm. The manipulator is a 6 d.o.f. robotic arm, the Aubo i5, which has a spherical workspace with an average radius of 93 cm. Robot Operating System (ROS) is used as a main framework for data communication between all the sub-processes of the robot. The Microsoft Kinect RGBD camera is attached to the end of the arm, whereas an Nvidia Jetson TX2 is used as onboard computing unit.

An example of point cloud of an office scenario is shown in Fig. 2. The figure depicts also the waypoints of the coverage path planning (green dots) and the end effector orientations derived from the surfaces' normals. The planned path is first simulated taking into account the 3D model of the manipulator as shown still in Fig. 2.

V. Conclusion

We presented a mobile robotic manipulator with a UV-C source for the disinfection of indoor environments. The proposed solution aims at providing an efficient and effective disinfection strategy which takes into account the, potentially complex, geometry of the environment. Experimental trials

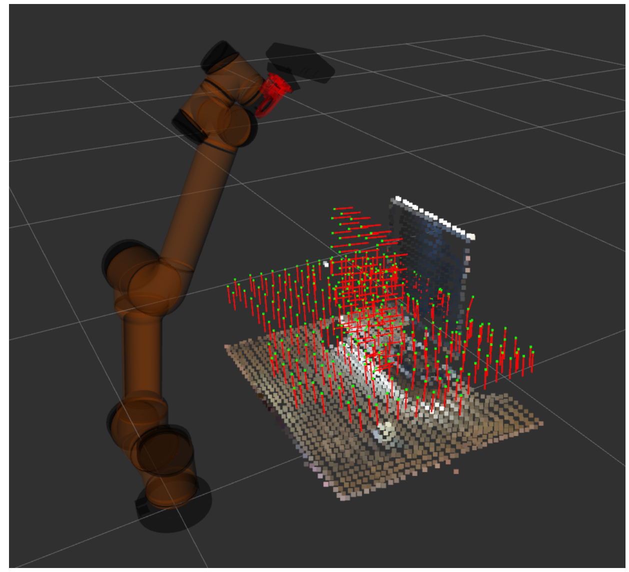

Fig. 2. An office environment (a desk and a monitor) reconstructed by the RGBD camera and the coverage path waypoints (in green) with their related end effector orientation (red segments).

with the involvement of microbiologists will be performed in order to validate the efficacy of the solution. As a future enhancement, we plan to include AI methods for object recognition within the RGBD camera perspective, in order to include specific disinfection policies for different types of materials and objects.

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