Design and Development of Multifunctional Autonomous Mobile Disinfection Robot against SARS-CoV-2 Virus

Tuan Nguyen Van, Nang Ho Xuan, and Nam Nguyen Duc
Phenikaa University, Hanoi 12116, Vietnam
Phenikaa Research and Technology Institute (PRATI), Hanoi 11313, Vietnam
Email: tuan.nguyenvan@phenikaa-uni.edu.vn, nam.nguyenduc@ phenikaa-uni.edu.vn

***Abstract*—Since 2019, coronavirus has impacted all aspects of humans and become one of the most serious pandemics in history. To prevent the spread of virus transmission in public, cleaning and disinfection with the support of technology are effective ways worldwide. The paper focuses on the design and development of a multifunctional autonomous mobile disinfection robot, namely MEM-Bot. The MEM-Bot integrates robust and well-developed technologies such as remote control, auto-navigation in a mobile platform with a biology/chemical solution to sanitization and disinfection effectively. The MEM-Bot consists of 8 UCV lamps with 240 W radiation with no restriction emitting area, a 360º spinning detergent system, a pair of retractable arms equipped with mist nozzles to cover the lower area of spraying, and a floor-cleaning module. The overall disinfection zone is cylindrical with a radius of 1 meter and a height of 3 meters. Fabricated at a much lower cost than commercialized robots, MEM-Bot has been rapidly deployed and tested at the Phenikaa University campus zone for months. The MEM-Bot is a potential solution for developing countries against the COVID-19.**

***Index Terms*—disinfection robot, UVC light, COVID-19, autonomous mobile robot, chemical detergents**

I. Introduction

Coronavirus is considered a once-in-a-century pandemic because of the high contagiousness and infection fatality rate [1]. Coronavirus can last about three days on plastic surfaces and stainless steel surfaces [2, 3]. Up to date, more than 527 billion people get infected and 6.28 billion die within 2 years. Recently, the Omnicron variant of SARS-CoV-2 has become a primary concern worldwide via its shorter incubation period and more fatality (Fig. 1). Billions of people have to take distance learning rather than go to campus for direct and offline education. Besides the social distancing principle, the concern of virus transmission on the campus is the method of disinfection. The cleaning process is one of the most important steps to prevent virus transmission. However, the cleaning process conducted by humans is highly dependent on the skill and professionalism of the service-in-charge person [4]. The re-use of cleaning towels without or limited sanitization even promotes the spread of bacterial and viral pathogens [3-5]. While the need for labor in cleaning services had been doubled to tripled in the last 2 years, the cost for manual cleaning has been tremendously increased because of the number of zone such as campus zones, offices, departments, apartments, museums, etc. On the other hand, robots embedded with advanced technologies provide very good solutions in many countries to reduce person-to-person contact and save human effort. In the COVID-19 pandemic, robots have been transferred to many aspects of life such as diagnosis, screening, disinfection, surgery, telehealth, care, and logistic [6-11].

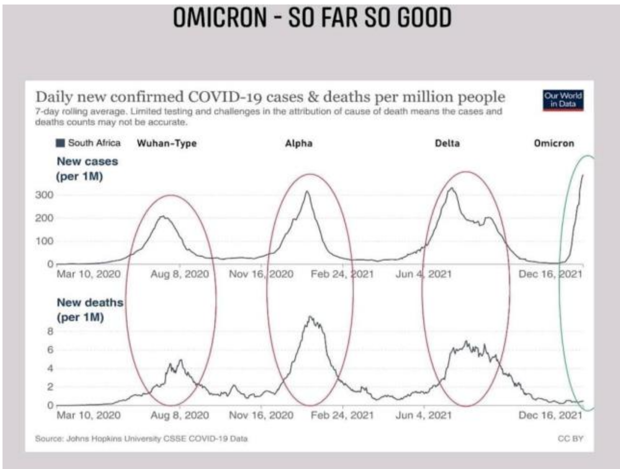


Figure 1. Daily new confirm COVID-19 cases & deaths per million people – Source: Johns Hopkins University. Updated by 16th December 2021.

One of the most popular robots joining the fight against COVID-19 is the disinfection robot [12-16]. Disinfection robots have been developed in a variety of designs and targets in a short time by both academic universities and technology companies worldwide such as Purdue University, University of Minnesota (USA), Lingnan University in Hong Kong, Nanyang Technological University (Singapore), Phenikaa-X (Vietnam), Akara, Xenex, UVD Robots (Fig. 2) . Current disinfection robots can be classified into UV light-based

Manuscript received February 11, 2022; revised June 1, 2022.

doi: 10.18178/ijmerr.11.10.718-723

and liquid-based disinfection mechanisms. Each of them has its advantages and drawbacks in reality.

Figure 2. Photos of UV-C robots: (a) Phenikaa – X, (b) Akara, (c) Xenex, and (d) UVD Robots (Source: Official websites).

Bacteria and viruses can be sterilized by using ultraviolet light with a wavelength from 100 to 280 nm (UV-C) [17-20]. At a distance of 1 meter, 20 joules per square meter per second of 254 nm light source can kill 99.99% of germs [21]. Nikita Mikhailovskiy et al [22] reported that 8 UV-C lamps with a total of 800 $\mu W/cm^2$ of 240 W radiation power are enough to kill 90% of microorganisms. A mobile robot can be transformed into UC-V light-based robot by adapting with UV light source module on top of them. These robots are integrated with sensors for navigation and obstacle detection such as cameras, LIDARS, infrared and ultrasonic sensors. More advanced mobile robots are equipped with sensors to perform simulated localization and mapping (SLAM) to navigate themselves and operate 24/7 without human supervision [8, 12, 15, 23-31].

One of the fundamental solutions which have been widely used in many countries is using chemical disinfectants such as peroxyacetic acid, chlorine dioxide, hydrogen peroxide, Alcohol, Formaldehyde; Glutaraldehyde, and Orthopthaladehyde [16]. These chemicals are highly effective for bacterial sanitization, air cleaners, especially in a large lockdown area. The main drawback of this is that the indoor cleaned space needs to be ventilated for a few hours a day to Richard Bormann et al [32] presented an autonomous robotic for office cleaning; however, the robot could perform with common trash rather than trivial pathogen-contained droplets. Tech-company such as Geek+ Technology Co., UBTECH use liquid agents to clean the floor and spray in the air. Kaicheng Ruan et al [33] integrated a wheeled mobile platform with a hydrogen peroxide atomization device to clean the indoor air without using a UV-C light source. The robot by K. Ruan et al [22] can kill up to 83.8% of air bacteria in a closed room. However, the COVID-19 virus can remain on the surface, droplets, and aerosols for more than 80 hours which leads to an ineffective solution if the robot can clean the airflow only. B. Casini et al [21] reported the importance of manual cleaning to disinfect bacterial and viruses in high-touch surfaces statistically and experimentally. It is relevant that manual cleaning by towel and liquid detergent is the first step to sterilizing the working space. However, the process will leave residues which requires time afterward.

Up to date, a large variety of disinfection robots integrated with different approaches have been used against the spread of the Coronavirus. The UVC light-based disinfection robot has limited usage over a large area or hidden areas under the shadow of objects. On the other hand, the liquid-based disinfection method is not effective in areas with gaps, holes, and complex surface structures where the spray droplet is hard to reach. As the result, a comprehensive approach is to combine these functions into one single mobile platform to maximize disinfection efficiency. In this research, we developed a novel idea for multifunctional and low-cost autonomous mobile robots applied in the dedicated zone such as campus zone, office apartments where the robot can implement the cleaning task at night without the presence of humans. The integrated mobile robot, namely **MEM-Bot**, can (i) disinfect bacterial and viral viruses by an intense UVC-light source, (ii) spinning detergent spraying system, and (iii) flexible floor-cleaning mechanism with a pair of the retractable arm to maximize the working space. Equipped with fundamental sensors such as LIDAR, ultrasonic sensor, and camera, the MEM-Bot can operate either automatically or manually. Since the hardware elements are well designed, MEM-Bot is a low-cost product leading to a high possibility to implement rapidly worldwide. MEM-Bot has been tested at Phenikaa University campus in Hanoi, Vietnam, and revealed a potential solution to apply robots and technology against the COVID-19 pandemic.

II. Design and Implementation of the MEM-Bot

A. *Design of the MEM-Bot*

The design of MEM-Bot is shown in Fig. 3. The robot consists of six main modules, i.e, (1) the mobile platform, (2) the intense UVC-light source module, (3) the spinnable detergent spraying system, (4) the retractable detergent spraying system, (5) the floor-cleaning module, and (6) hardware.

The mobile platform

The mobile platform is a configurable Automated Guided Vehicles (AGV) with a dimension of 750 x 560 mm (length x width). The mobile platform is driven by two independent driving wheels to maximize maneuverability in a complex workspace. MEM-Bot is powered by a 12V – 60A battery allowing it to work continuously for up to 2 hours per single charge. An 8 - litters detergent tank is located at the back of the platform and is extendable to 20 litters for outdoor spraying tasks where more intense sanitization is needed. The battery and detergent tank are interchangeable with ease; hence, the user can change the battery and fill the tank in several minutes.

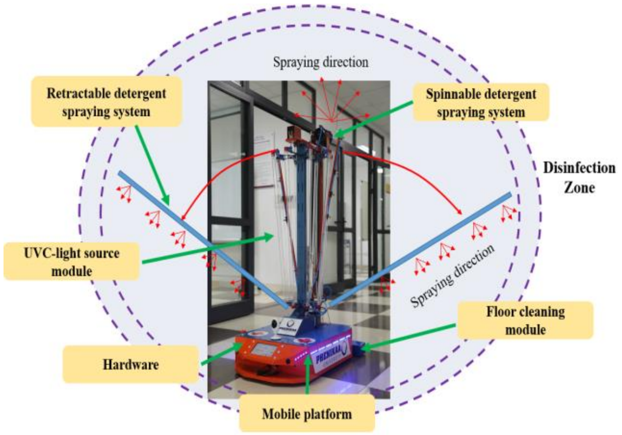


Figure 3. Overview of MEM-Bot design and modules. The overall disinfection zone of MEM-Bot is 1 meter in radius and 3 meters in height.

The intense UVC-light source module

Eight UV-C lamps with a total power of 240W were installed equally around the main structure. These eight lamps guarantee a disinfection zone by UVC-lights up to 2 meters in radius and prevent 90% of microorganisms similar to Nikita Mikhailovskiy's report [22]. It is worthy to note that compared to others disinfection robots such as robots from UltraBot, Xenes, Akara, and MIT, MEM-Bot was equipped with eight instead of four or six UVC lamps so that the radiation intensity is 1.5 to 2 times larger [5]. Therefore, MEM-Bot can operate less time consuming than the others with equivalent specifications.

The spinnable detergent spraying system

It is a great concern that many respiratory viruses can transmit over multiple routes such as droplets and aerosol transmission paths. This environment remains in the vapor phase and flies together with mist in the air. Air disinfection is always one of the first act as virus source is detected. Therefore, a high-pressure spraying mechanism is designed at the top of the main structure. This spraying module can rotate freely and cover to the height of 3 meters.

The retractable detergent spraying system

While the spinnable detergent spraying system covers the top space of the disinfection zone, the lower space is covered by a pair of retractable wings. When MEM-Bot operates in the hallway or outdoor area, 1-meter length arms are opened to maximize the effective area. In the classroom, where the path is limited, and/or during transportation, these arms are retracted. Such an innovative idea allows MEM-Bot to implement the task on the different maps with high details.

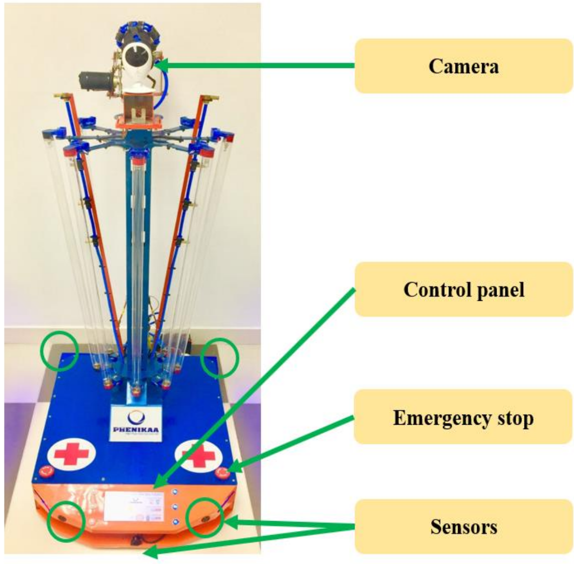
The floor-cleaning module

After a few hours of spraying detergent, chemical residues remain on the floor and need to be cleaned. At the rear of MEM-Bot, there is a floor-cleaning module to accomplish this mission.

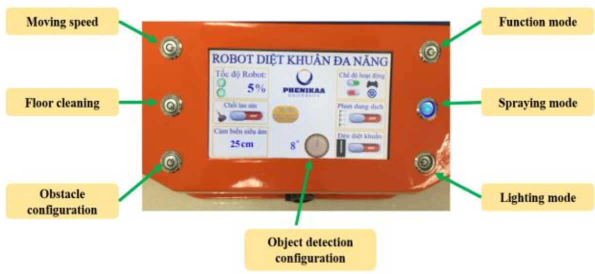
B. Hardware and Control System of the MEMS-Bot

The hardware of the MEM-Bot

The MEM-Bot is equipped with several sensors to operate in both manual and autonomous mode. Four ultrasonic sensors were installed at the corners and a Lidar (RPLIDAR-A1, SLAMTEC) was used for the auto-navigation mission (Fig. 4a). In the manual mode, the operator used a controller to directly manipulate remotely with functions such as spraying, lighting, cleaning, maneuvering, etc. On the other hand, the autonomous mode can be pre-set by the use of the Nextion 7.0 inch capacitive touchscreen display and a series of physical buttons (Fig. 4b).



(a)



(b)

Figure 4. (a) Sensors equipped for MEM-Bot, and (b) Control Panel

Control system of the MEM-Bot

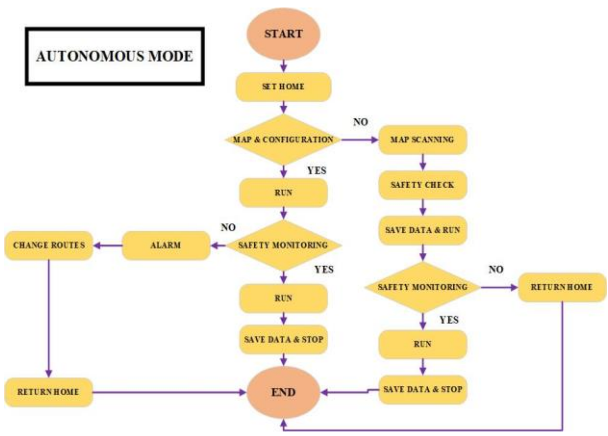


Figure 5. The flowchart of the autonomous mode of the MEM-Bot

We used a mini-computer Raspberry Pi 4 board and an STM32F407VGT6 embedded board to process the control. The detailed control flowchart of autonomous mode is shown in Fig. 5. In manual mode, the moving path and configuration such as speed, light source, spraying mode were recorded and saved to the memory along with the scanned map. Hence, based on the specific map, the user needs to config once, then he can replicate such data for the next time of disinfection. This function allows the ease of operation with little training time for low-skill workers and quick response for emergencies.

III. Results and Discussion

The MEM-Bot has been deployed and tested in the Phenikaa University campus zone for 6 months. Within this period of testing time, there was no record of the coronavirus transmission throughout the surfaces in the classroom and the hallway. The classroom and workshop room was considered indoor while the lobby and hallway were taken into account as outdoor conditions. Each classroom is 6 meters (width) x 7 meters (length) on average and has a 2-meter wide main lobby. The furniture inside the room is currently unchanged after each class. The MEM-Bot was tested in the daytime and at night. It took approximately 10 minutes to disinfect a 42-meter squares classroom and 15 minutes for a 2.5-meter wide hallway. Only one operator is required to monitor the operation of MEM-Bot and to refill the detergent tank manually. At the Department of Mechanical Engineering and Mechatronics, Phenikaa University, an average of one hour and 20 litters of detergent liquids was needed for one floor (Fig. 6).

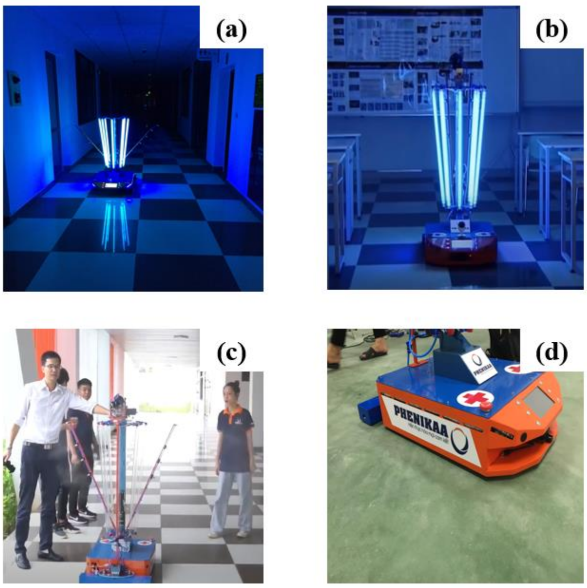


Figure 6. Experimental test at Phenikaa University campus: (a) in the hallway at night, (b) in the classroom at night, (c) in the hallway at day time, and (d) floor-cleaning function.

Compared to published disinfection robots, MEM-Bot has not been integrated with smart sensors and advanced technology such as AI algorithm to detect and classify obstacles such as humans, furniture, etc. MEM-Bot's operation time is the weekend, night, and day-off period when there is a limitation of humans. Since the side-effect of UVC light on human parts such as skins and eyes, it is recommended not to directly emit the UVC light to the human parts. However, to increase the safety function, the detection and classification algorithm applied in MEM-Bot is in progress. Two other important functions are also developed in the next version of MEM-Bot. They are an electric charging system and detergent charging system. Currently, these procedures are accomplished by the operator which still requires the human's contribution partly.

The demo videos are can be viewed in URL [34, 35] and the specifications of the MEM-Bot are listed in Table I.

TABLE I. MEM-Bot Specification

Description	Specification	Note
General		
Weight	100 kg	
Dimension	750 x 560 x 1300 (mm)	Extendable to 750 x 2500 x 1300 mm full range
Battery	12V, 7Ah	8 pieces
Endurance	2 h	Per single charge
Speed	0.75 m/s	Maximum speed
UVC lamp	8 lamps UVC lamp, 254nm wavelength, 240 W in total	360^o radiation
Detergent tank capacity	8 L	Extendable to 20L
Spray capacity	5 – 6 L/h	
Number of spraying nozzles	22	
Effective disinfection zone	Cylindrical effective zone, 1 meter in radius, 3 meters in height	Combination of UVC and spraying disinfection method
Function		
Disinfection method	UVC light, Chemical disinfectant	
Operation	Manual, Automatic	
Navigation and safety	LIDAR, Ultrasonic sensor	
Monitoring	FPV Camera	
Remote protocol	WiFi	
Additional function	Floor cleaning	
Cost	5000 USD	

IV. Conclusion

The Omnicon variant is now the main concern in many countries causing great influence to everyone, especially students. To respond quickly to the spread of the virus, the main challenge is to rapidly apply technology such as the disinfection mobile robots. This paper presents a novel solution to support humans in the campus zone where the human is absent at night so that the cleaning by UVC light and chemicals will not cause any side effects. The MEM-Bot sanitizes the pathogen droplets and aerosol with 8 UVC lamps and a combination of spraying systems. The disinfection efficiency of UVC-light and liquid-based detergent in MEM-Bot follow the relevant proof by numbers of research groups. The prevention mechanism creates a disinfection zone up to 1 meter in radius by 3-meter height. The MEM-Bot system incorporates basic technologies including route planning, navigation, obstacle detection, and teleoperation. These robust designs and algorithms enable the MEM-Bot to manually or automatically complete disinfection throughout many kinds of environments. Thereby, human safety from vital viruses/bacteria is quarantined and reduces the labor effort significantly. More effort is needed to commercialize the MEM-Bot with lower cost, more robust control, and more adaptive usage for various types of laborers' skills.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Tuan Nguyen Van, Nam Nguyen Duc contributed to the analysis and implementation of the research, to the analysis of the results and to the writing of the manuscript.

All authors discussed the results and contributed to the final manuscript. Besides, Nang Ho Xuan conceived the study and were in charge of overall direction and planning.

Acknowledgment

This research was supported financially by the Phenikaa University, Viet Nam.

References

[1] K. M. Agarwal, et al., "Study and overview of the novel corona virus disease (COVID-19)," *Sens Int, vol.* 1, p. 100037, 2020.

[2] R. Suman, et al., "Sustainability of coronavirus on different surfaces," *J Clin Exp Hepatol*, vol. 10, no. 4, pp. 386-390, 2020.

[3] F. Petrosino, et al., "Transmission of SARS-Cov-2 and other enveloped viruses to the environment through protective gear: a brief review," *EuroMediterr J Environ Integr*, vol. 6, no. 2, p. 48, 2021.

[4] M. Jayaweera, et al., "Transmission of COVID-19 virus by droplets and aerosols: A critical review on the unresolved dichotomy," *Environ Res*, vol. 188, p. 109819, 2020.

[5] A. J. J. N. B. S. C. A. M. C. A. M. S. D. C. K. J. K. M. M. M. S. A. Pozzi, "Review of sterilization techniques for medical and personal protective equipment contaminated with SARS-CoV-2," *IEEE Access*, vol. 8, p. 111347, 2020.

[6] Y. Shen, et al., "Robots under COVID-19 pandemic: A comprehensive survey," *IEEE Access*, vol. 9, pp. 1590-1615, 2021.

[7] M. Diab-El Schahawi, et al., "Ultraviolet disinfection robots to improve hospital cleaning: Real promise or just a gimmick?" *Antimicrob Resist Infect Control*, vol. 10, no. 1, pp. 33, 2021.

[8] M. Nasajpour, et al., "Internet of things for current COVID-19 and future pandemics: An exploratory study," *J Healthc Inform Res*, vol. 4, no. 4, pp. 325-364, 2020.

[9] D. J. Anderson, et al., "Decontamination of targeted pathogens from patient rooms using an automated ultraviolet-C-emitting device," *Infect Control Hosp Epidemiol*, vol. 34, no. 5, pp. 466-471, 2013.

[10] D. J. Gadzinski, A. J., et al., "Telehealth in urology after the COVID-19 pandemic," *Nat Rev Urol*, vol. 17, no. 7, pp. 363-364, 2020.

[11] M. Doll, et al., "Touchless technologies for decontamination in the hospital: A review of hydrogen peroxide and UV devices," *Curr Infect Dis Rep*, vol. 17, no. 9, pp. 498, 2015.

[12] Z. Zhao, et al., "Applications of robotics, artificial intelligence, and digital technologies during COVID-19: A review," *Disaster Med Public Health Prep*, pp. 1-11, 2021.

[13] S. Sarker, et al., "Robotics and artificial intelligence in healthcare during COVID-19 pandemic: A systematic review," *Rob Auton Syst*, vol. 146, p. 103902, 2021.

[14] M. Guettari, et al., "UVC disinfection robot," *Environ Sci Pollut Res Int*, vol. 28, no. 30, pp. 40394-40399, 2021.

[15] G. G. Cengiz Deniz, "A new robotic application for COVID-19 specimen collection process," *Journal of Robotics and Control (JRC)*, vol. 3, no. 1, 2022.

[16] Y. L. Z. H. P. H. T. L. C. P. C. C. Y. H. C. J. H. Y. C. H. H. J. F. L. W. T. Weng, "A smart sterilization robot system with chlorine dioxide for spray disinfection," *IEEE Sensors Journal*, vol. 21, no. 19, 2021.

[17] M. Biasin, et al., "UV-C irradiation is highly effective in inactivating SARS-CoV-2 replication," *Sci Rep*, vol. 11, no. 1, p. 6260, 2021.

[18] F. Astrid, et al., "The use of a UV-C disinfection robot in the routine cleaning process: A field study in an Academic hospital," *Antimicrob Resist Infect Control*, vol. 10, no. 1, p. 84, 2021.

[19] C. Rock, et al., "Ultraviolet-C light evaluation as adjunct disinfection to remove multi-drug resistant organisms," *Clin Infect Dis*., 2021.

[20] J. H. Yang, et al., "Effectiveness of an ultraviolet-C disinfection system for reduction of healthcare-associated pathogens," *J Microbiol Immunol Infect*, vol. 52, no. 3, pp. 487-493, 2019.

[21] B. Casini, et al., "Evaluation of an Ultraviolet C (UVC) light-emitting device for disinfection of high touch surfaces in hospital critical areas," *Int J Environ Res Public Health*, vol. 16, no. 19, 2019.

[22] N. Mikhailovskiy, S. Alexander, S. Perminov, I. Kalinov, D. Tsetserukou, "UltraBot: Autonomous mobile robot for indoor UV-C disinfection with non-trivial shape of disinfection zone," in *Proc. 26th IEEE International Conference on Emerging Technologies and Factory Automation (ETFA)*, 2021.

[23] P. Rizuwana, E. A., "Autonomous self-reconfigurable floor cleaning robot," *IEEE Access*, vol. 8, pp. 114433-114442, 2020.

[24] L. Al-Zogbi, et al., "Autonomous robotic point-of-care ultrasound imaging for monitoring of COVID-19-induced pulmonary diseases," *Front Robot AI*, vol. 8, p. 645756, 2021.

[25] A. Pani, et al., "Evaluating public acceptance of autonomous delivery robots during COVID-19 pandemic," *Transportation Research Part D: Transport and Environment*, vol. 89, p. 102600, 2020.

[26] L. El Haddad, et al., "Evaluation of a pulsed xenon ultraviolet disinfection system to decrease bacterial contamination in operating rooms," *BMC Infect Dis*, vol. 17, no. 1, pp. 672, 2017.

[27] M. M. Nerandzic, J. L. Cadnum, M. J. Pultz, C. J. Donskey, "Evaluation of an automated ultraviolet radiation device for decontamination of Clostridium difficile and other healthcare-associated pathogens in hospital rooms," *BMC Infectious Diseases*, vol. 10, no. 197, 2010.

[28] S. Sahloul, et al., "An hybridization of global-local methods for autonomous mobile robot navigation in partially-known environments," *Journal of Robotics and Control (JRC)*, vol. 2, no. 4. 2021.

[29] R. Bormann, J. H., M. Hagele, "New brooms sweep clean - an autonomous robotic cleaning assistant for professional office cleaning," in *Proc. IEEE International Conference on Robotics and Automation (ICRA)*. 2015: Seattle, Washington, USA. p. 4470.

[30] B. K. Patle, et al., "A review: On path planning strategies for navigation of mobile robot," *Defence Technology*, vol. 15, no. 4, pp. 582-606. 2019.

[31] G. N. Moawad, et al., "Robotic surgery during the COVID pandemic: why now and why for the future," *J Robot Surg*, vol. 14, no. 6, pp. 917-920, 2020.

[32] D. H. Sliney, et al., "A need to revise human exposure limits for Ultraviolet UV-C Radiation(dagger)," *Photochem Photobiol*, vol. 97, no. 3, pp. 485-492, 2021.

[33] K. Ruan, et al., "Smart cleaner: A new autonomous indoor disinfection robot for combating the COVID-19 pandemic," *Robotics*, vol. 10, no. 3, p. 87, 2021.

[34] N. V. Tuan, N. D. Nam, N. H. (2021). *MEM-Bot demo video*. [Online]. Available from: https://youtu.*be*/S434NYgkLUs
[35] N. V. Tuan, N. D. Nam, N. H. (2021). *MEM-Bot reported by Vietnam National Television*. [Online]. Available from: https://youtu.be/G_QEtXILgJE.

Tuan Nguyen Van received his B.Eng. in Mechanical Engineering from Hanoi University of Science Technology, Vietnam, in 2009. He received the Master degree in Mechatronics Engineering from Hanoi University of Science Technology in 2015. He is currently pursuing a Ph.D. degree with the School of Mechanical, Hanoi University of Science Technology, Vietnam.
Currently, he is a lecturer at Faculty of Mechanical Engineering and Mechatronics, Phenikaa University, Vietnam.
His research interests include control, autonomous underwater vehicle, robotics and automation system.

Nam Nguyen Duc received his B.Eng. in Mechatronics Engineering from Hanoi University of Science Technology, Vietnam, in 2011. He obtained his PhD. In 2019 in Mechanical Engineering from Pohang University of Science and Technology, Korea.
Currently, he is a lecturer at Faculty of Mechanical Engineering and Mechatronics, Phenikaa University, Vietnam.
His research interests include control, smart mechatronic system and automation system.

Nang Ho Xuan received the Ph.D. degrees from Hanoi University of Science Technology, Vietnam. Currently, he is a lecturer at Faculty of Mechanical Engineering and Mechatronics, Phenikaa University, Vietnam. His research interests include numerical optimization and systems engineering.