# Robotic Systems on the Frontline Against the Pandemic

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**Abstract.** Robotic systems have been effectively used in healthcare while a new role for them has emerged during the COVID-19 pandemic. Robots were used as part of prevention, screening and diagnosis of the disease, but also to assist with the treatment of patients. The purpose of the paper is to provide an overview of the relevant applications for robots and highlight their potential.

**Keywords:** Sterilization/Disinfection robots · Nursing robots · Service robotics

## 1 Introduction

Applications of robotics in healthcare are rapidly increasing with the International Federation of Robots (IFR) forecasting a growing demand for robots in the healthcare sector, estimated at 9.1 billion USD by 2022 [1]. Robots in clinical practice also include surgical systems [2] and nursing robotics [3]. Following the novel coronavirus crisis (COVID-19) a new role for robotics has emerged towards the combat of a pandemic.

Among the successful implementations are included autonomous robotic solutions employed in hospitals for disinfection using ultraviolet (UV) lights or using fog/mist disinfectants. As part of screening programs, robots were employed for temperature measurements. They may also facilitate samples collection while minimizing physical contact. Laboratory testing often involves robots for the processing of samples. As part of patient treatment, nursing robots can assist with delivery tasks within a hospital (medicine, food trays, contaminated waste etc.), effectively reducing physical contact and exposure to diseases. Different roles for mobile robots include supervision of social distancing in public areas and issuing of reminders when required. Their use may also be extended to the policing of quarantine areas.

A considerable number of relevant robotic systems has recently been developed and commercialized, which is indicative of the quick response of the robotics community to the pandemic. Universities developed prototypes to investigate different concepts but


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companies were quick to exploit the generated market potential and business opportunities. A collection of relevant robotic systems is shown in Table 1, which is not exhaustive but is representative of the field and provides a basis for reviewing the relevant developments. Websites that are referenced were accessed at the time of publication.

The paper is organized as follows. Section 2 focuses on the preventive roles of robotic systems, i.e., sterilization/disinfection applications. Section 3 presents their screening and diagnosis role, while Sect. 4 focuses on telemedicine and nursing robots. The final section presents the conclusions and directions for further developments.

## 2 Prevention – Sterilization/Disinfection Robots

Disinfection and sterilization of common areas, rooms, corridors, laboratories and clinical areas is a preventive step against the spreading of infectious diseases. Current cleaning practices and procedures in hospital settings is based on human resources and in many cases, it proves ineffective, cumbersome, time consuming and costly. The use of robotics in the disinfection process has been increasing rapidly. They are suitable for large-scale deployments in healthcare facilities [4] and they typically comprise a mobile platform mounted with appropriate disinfection equipment.

Systems are divided into two categories on the basis of the implemented disinfection method: (a) disinfection using C-band ultraviolet lights (UVC); (b) disinfection using fog/mist disinfectants. On the basis of autonomy levels, systems can be: (a) remotely-controlled; (b) semi-autonomous; (c) autonomous. The last one is particularly challenging given that robots are required to operate in a dynamic, populated environment with expensive equipment. Autonomous functions for the mobile platform may include collision avoidance systems, autonomous charging, mapping and localization. Note that autonomy may refer to the motion of the robot and/or the sterilization process.

The most suitable disinfection method for a given case depends both on the application and the environment [5]. In general, UVC-based procedures are more effective when employed in settings with various types of surfaces such as tables, beds, walls and floors. As UV radiation may cause damage to organic tissue (skin burns and skin cancer), its use is not recommended in human-populated areas and fogging-based disinfection methods are more suitable. Moreover, exposure of the eyes to UV light can produce serious vision impairments. The effectiveness of germicidal UV disinfection depends on direct UV light exposure and duration. For the above reasons, a robot constitutes a suitable agent for effective and safe, large-scale implementations. Compared to fixed systems (mounted or portable) with a limited coverage, the use of robotics may enhance the effectiveness, flexibility and safety of the disinfection process.

Relevant systems which have been developed for UV disinfection, they typically consist of a mobile robotic platform on which is installed an array of ultraviolet lamps (e.g., [6–10]). The mobile platform is often equipped with sensors for collision prevention. The lamps arrangement is such that shadowing is avoided and coverage is maximized. One example is the Helios® System shown in Fig. 1a, which uses multiple light-emitting robots (a trio) in a single cycle of disinfection, to improve efficiency and reduce time [9]. Another commercial example shown in Fig. 1b, is the LumniCleanse UV-C (OMRON) robot. It is a wireless, remotely-operated, autonomous disinfection robot integrated with 16 UVC-emitting lamps. Its batteries allow for up to 3 h of operation [10].

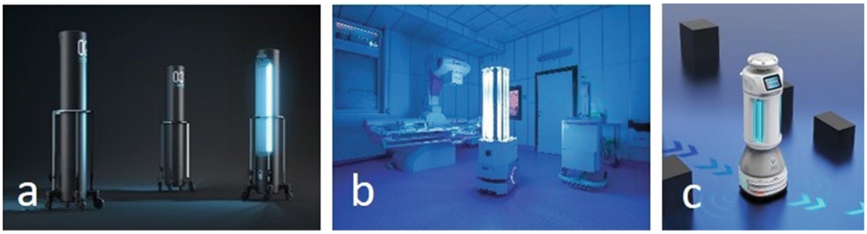


**Fig. 1.** Robots used in disinfection. (a) Surfacide Helios® System (photo courtesy of Surficide); (b) LumniCleanse UV-C robot (photo courtesy of Lumnicleanse Ltd); (c) Keenon Robot (photo courtesy of Keenon Robotics)

To increase their usefulness some disinfection robots are installed with extra functions, as for example the autonomous system in [11], which is also equipped with a human body temperature camera. Systems can often be operated in different control modes, as for example the disinfection robot [12], which can be operated autonomously, semi-autonomously (staff is required to open doors), or manually via a wired controller. It can be used as a single device or in a connected fleet. Safety laser scanners at the front and rear of the robot allow it to detect obstacles and people when in transit. Systems may also be endowed with advanced robot control capabilities, as for example in the case of the UVD Robot® [13]. The system does environment scanning using LiDAR technology and creates a digital map. It then relies on Simultaneous Localization and Mapping (SLAM) to navigate and operate autonomously. Its operation is suspended when the presence of a person is detected. It can also be driven manually from a distance, while the operator uses the onboard cameras to navigate via a tablet.

The next category of disinfection robots uses fog/mist disinfectants. A comparative evaluation of the operating room cleaning using an ultraviolet light method versus a manual chemical disinfection can be found in [14]. An example of such a robot is [15], which uses an atomizing or fogging system to coat surfaces, while operated wirelessly from outside a hospital room. In the case of [16], the disinfection process is monitored by integrated sensors, is registered and reports are generated. A unique case is [17], which comprises a wheeled robot installed with a 6 degree-of-freedom arm manipulating an electrostatic charged sprayer for chemical disinfection. This arrangement provides access to difficult-to-reach locations. Robot navigation is semi-autonomous, while the arm is wirelessly controlled manually. The system may be endowed with intelligence not only with regard to the mobile platform but also the disinfection subsystem itself, as in the case of [18]. A camera system coupled with an intelligent vision algorithm allows the operator to remotely locate affected areas. A distinct example that combines two disinfection methods for increased efficiency [19], is the Keenon robot shown in Fig. 1c. It is installed with a UV sterilization module and a spray disinfection module. Beyond an intelligent obstacle avoidance system, it also has a fully autonomous positioning and navigation system suitable for complex environments. Moreover, a multirobot configuration can be implemented. Another system that combines multiple disinfection methods is [20]. It moves autonomously using a map of the facilities. It integrates three disinfection modes: ultraviolet, ultra-dry vaporized hydrogen peroxide, and air filtration.

## 3 Screening and Diagnosis Robots

Early and timely detection of infected individuals is crucial for the effective management of infectious diseases. Telemedicine provides methods and techniques enabling doctors and patients to communicate without coming into physical contact [21]. Respiratory symptoms and high body temperature are early signs of COVID-19 infection.

Body temperature monitoring systems using robots are well-suited to highly crowded public places such as airports, schools and subway stations. An implementation example for temperature measurement is the case of [22]. Thermal sensors and relevant vision algorithms have been integrated into autonomous or remotely-operated robots to improve screening efficiency. The Misty II robot (shown in Fig. 2) is a small-size screening system equipped with a thermal imaging camera and is supported by an application [23]. It has built-in face detection and face recognition capabilities. The screening procedure also involves some interactive questions. Configurable SMS, email notifications, as well as web-based administration and reporting are available.


**Fig. 2.** Misty II screening robot (Photo courtesy of Misty Robotics)

Commercial robot models by UBTECH [24, 25] were employed as UVC disinfection solutions, for performing temperature checks for visitors, as well as interactively asking health questions while entering the facilities. They were also used to check people in public areas if they wear face masks correctly. Using their ability to navigate autonomously they were also used in performing crowd density monitoring and issuing of reminders to implement social distancing. A different temperature screening system suitable for outdoor environments is presented in [26] and allows two modes of operation. One is for drivers and passengers of mobile vehicles and the other is for pedestrians. Capability for additional measurements was included on a robotic platform teleoperated by trained clinical stuff, for remotely obtaining vital signs associated to COVID-19 patients evaluation [27]. Measurements include skin temperature, respiratory rate, heart rate, and blood oxygen saturation.

The use of robots in automatic swab sample process has also been considered, as in [28]. This robot is capable of carefully collecting the swab from the correct point in the throat, using computer vision algorithms. The sample is prepared and appropriately labelled before is sent for laboratory analysis. A different robot for swab sampling while reducing the risk of cross-infection involves a snake-like arm and an endoscope for image guidance [29]. In the same category is a low-cost miniature robot for nasopharyngeal swap sampling, which was presented in [30]. It consists of a 6-DOF passive arm for

**Table 1.** Robotic systems deployed against the COVID-19 pandemic.

| No | Name | Company-Institution | Purpose | Ref. |
|---|---|---|---|---|
| 1. | LightStrike | Xenex, USA | Disinfection | [6] |
| 2. | E300 | Purplesun, USA | Disinfection | [7] |
| 3. | LASKA & Yezhik UVD Robots | Aitheon, USA | Disinfection | [8] |
| 4. | Helios UV-C | Surfacide, USA | Disinfection | [9] |
| 5. | LumniCleanse UV-C | LumniCleanse, UK | Disinfection | [10] |
| 6. | ARIS-K2 | Youibot Robotics Co., Ltd. | Disinfection Screening | [11] |
| 7. | Mini$^{TM}$ UVC | BlueBotics & Engmotion, Switzerland | Disinfection | [12] |
| 8. | UVD Robot | UVD Robotics, Denmark | Disinfection | [13] |
| 9. | Nimbus | Nevoa, USA | Disinfection | [15] |
| 10. | DeconX | Decon-X, Norway | Disinfection | [16] |
| 11. | XDBOT | NTU, Singapore | Disinfection | [17] |
| 12. | Disinfection Robot | SIEMENS & AUCMA | Disinfection | [18] |
| 13. | Keenon Robot | Keenon Robotics, China | Disinfection | [19] |
| 14. | Tmi Robot | TMIRob, China | Disinfection | [20] |
| 15. | Misty II Robot | Misty Robotics | Screening | [23] |
| 16. | CRUZR | UBTECH, China | Screening | [24] |
| 17. | AIMBOT | UBTECH, China | Screening | [25] |
| 18. | SHUYU Robot | Tsingke+ Robot Joint Research Institute Co., Ltd, China | Screening | [26] |
| 19. | Dr. Spot | Boston Dynamics | Screening | [27] |
| 20. | Careebo LLR S1 | Lifeline Robotics, Denmark | Screening-Diagnosis | [28] |
| 21. | OP-Swab Robot | Guangzhou Institute of Respiratory Health, China | Screening-Diagnosis | [29] |
| 22. | Swab Sampling | Wang et al. | Screening | [30] |
| 23. | Flowbot ONE | Flow Robotics, Denmark | Screening - Laboratory | [31] |
| 24. | Ultrasound Robot | Tsinghua University, China | Screening- Diagnosis | [35] |
| 25. | Moxi | Diligent Robotics, USA | Nursing | [37] |
| 26. | TRINA | Duke University's School of Engineering and School of Nursing | Nursing | [36] |

global positioning and a 2-DOF end-effector for the actual sampling. The role of robotics also extents to the laboratory testing of collected samples, as in the case of a pipetting, liquid-handling robot that is used to make the process more efficient and faster, while minimizing the possibility of errors and the risk of infection [31].

## 4 Telemedicine and Nursing Robots

The recent pandemic caused an enormous burden on healthcare systems, while healthcare professionals are themselves highly exposed to the disease. Telehealth has been enlisted as an effective method that allows patients having COVID-19 symptoms to be examined and monitored [32]. The use of teleoperated robots capable of performing ultrasound examinations from a distance [33] may effectively help in diagnosis and health monitoring, while preventing cross-contamination. A telerobotic ultrasound system was considered for cardiopulmonary assessment of COVID-19 patients in [34]. Also, Akbari et al. [35] presented the case of US probe manipulation by a dexterous robot arm, effectively minimizing the contact between healthcare professionals and patients.

The use of nursing robots [3] has been attracting renewed attention towards reducing physical contact between healthcare professionals and patients [36]. They may also help to reduce the usage of personal protective equipment and also avoid contamination during its removal. Robots may undertake different roles including distribution of medication and food, patient monitoring, and support with patient ambulation. From a psychological perspective, robots may help provide patients with the means to remain socially connected when hospital visits are not permitted.

A commercial system called Moxi (Diligent Robotics) belongs to the above family of robots and is marketed for running patient supplies, delivering lab samples, bringing items from central supply, and delivering medications [37]. Another representative system is TRINA, which consists of a mobile manipulator robot and a human operator's console. It provides assistance to medical staff to perform routine tasks, such as carrying food and medicine, cleaning, and monitoring vital signs while at the same time communicating with the patient [36].

## 5 Conclusions

Robotic solutions were successfully deployed in response to the COVID-19 pandemic with applications ranging from prevention, screening and diagnosis, as well as assistance with patients' treatment. These implementations are expected to nurture further research and development in the field. The robotics technology itself has to adapt to the application needs with robots becoming more intelligent, user friendly and safe. Integration of the robotics technology and the application-specific equipment (e.g., sterilization lights) may yield more effective, safe and cost-effective solutions. The full potential of nursing robotics and robot deployments towards the prevention and management of infectious diseases is yet to be exploited.

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