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Robotics, Smart Wearable Technologies, and Autonomous Intelligent Systems for Healthcare During the COVID-19 Pandemic: An Analysis of the State of the Art and Future Vision

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This article presents how robotic and autonomous systems and smart wearables can complement and support healthcare delivery and the healthcare staff during the COVID-19 pandemic. For instance, robotic and telerobotic systems can significantly reduce the risk of infectious disease transmission to frontline healthcare workers by making it possible to triage, evaluate, monitor, and treat patients from a safe distance. We provide various examples of where the medical, engineering, and science communities can come together to aid the healthcare system, healthcare workers, and society during the current crisis. The goal is to encourage an interdisciplinary dialog so that together we can find ethical, practical, and beneficial technological solutions to effectively tackle this and similar crises.

KEYWORDS
COVID-19, Healthcare, Robotics, Wearable Technology, Autonomous Systems

1 | INTRODUCTION

The 2019-2020 novel coronavirus (COVID-19) pandemic is characterized by the exponential growth of the infection, catching societies, healthcare systems, and governments off-guard. The reproduction number R_0, defined as the average number of cases an infected person will cause, is used to calculate the worst-case epidemic potential of a pathogen. While diseases with $R_0 < 1$ die out in a population, an estimated R_0 between 1.5 to 3.5 for the novel coronavirus has made it highly transmissible and responsible for a global health crisis unlike any in the 75-year history of the United Nations [1].

In the lack of any vaccine or proven antiviral treatment, actions in terms of prevention, containment, and mitigation are mainly achieved through good hygiene, social distancing, curfews, travel restrictions, and large-scale screening across susceptible and high-risk populations in addition to quarantines, isolation measures, and hospitalization in the exposed, suspicious or positively tested population. We argue here that intelligent robotics and autonomous systems, as well as smart wearables, can play a positive role. They can facilitate the prevention, containment, and mitigation of COVID-19 and provide general support for patients and medical professionals, alleviating the non-COVID-19 burden placed on healthcare systems during this crisis.

2 | THE OUTBREAK: CHALLENGES AND CONSEQUENCES

At the start of the outbreak, a lack of accurate and reliable information about the disease, misdiagnosis of the novel coronavirus as flu, and the continuation of global business and travel exacerbated the worldwide spread of the virus. At the present time, some of the main factors that continue to complicate the containment and mitigation efforts include a delay of 2-14 days between exposure and onset of symptoms, the spread of infection by asymptomatic carriers in this incubation period, and limited healthcare capacity worldwide in terms of the available number of hospital beds, trained staff, and medical equipment to support the symptomatic patients including the critically ill cases in intensive care units (ICUs). Globally, the most critical medical equipment shortages are related to testing kits, ventilators, and personal protective equipment (PPE) such as N95 respirators, surgical masks, face shields, and gowns. PPE is currently needed in very large quantities both due to the number of cases and the fact that the chances of infection are higher in hospitals and even higher in ICUs.

Aside from the direct and obvious challenges posed by the novel coronavirus pandemic, there are serious and growing secondary consequences caused by focusing almost all available healthcare capacity on fighting the pandemic. The all-out war on the pandemic has come at the cost of pausing or severely limiting the less urgent care including outpatient procedures such as annual physical exams, bloodwork, colonoscopies, and mammograms, X-rays, MRIs, and other types of imaging. In many countries, care for non-life-threatening chronic illnesses has been almost completely deferred to the future. In addition to the obvious impact on affected patients, this is creating a growing backlog of procedures and treatments to be addressed in the future.

At the time this article is written, worldwide there are over two million cases of patients with a confirmed link to COVID-19. Across the globe, many businesses and services have been closed with severe consequences for trade, jobs, and economies. Economists are predicting that the coronavirus will plunge the world into a recession much worse than the global financial crisis of 2008. The disruption in the global supply chains caused by the pandemic has further intensified the shortage of medical equipment and PPE, which has, in turn, led to the spread of the virus among the very medical workers who are fighting it. Other workers in charge of ensuring the continuity of essential services such as governance, police and firefighting, water and electricity, food manufacturing and distribution, and transportation face an increased risk of infection as well.

3 | THE ADVANTAGES OF AUTOMATION

It is interesting to note that where automation solutions were deployed previously, COVID-19 has done the least amount of disruption. For example, Amazon's heavy investment in robotic automation within its fulfillment centers proved worthwhile because it allowed robust shipment of crucial medical supplies to hospitals and of household staples to homes of people ordered to stay indoors [2]. Many companies have started in recent years to trial autonomous goods delivery systems, including vision-guided self-navigating ground and airborne robots, which can be potentially life-saving during this pandemic. While not necessarily robotically enabled, smartphone apps for ordering food and automation technologies such as video-conferencing for virtual work from home have enabled broader self-isolation than would have been possible in the past. One issue that may still threaten global supply chains is their heavy reliance on human operators, including truck drivers, cargo ship crew, and port crane operators to maintain the flow of cargo. Autonomous long-haul trucking, self-piloting ships, and automated cranes are emerging technologies that would have been highly advantageous in this crisis. Last but not least, the utility of 3D printing has come to the forefront during the COVID-19 pandemic. 3D printing has been employed in this crisis by the amateur community for making crowd-sourced do-it-yourself supplies for frontline healthcare workers and by businesses to speed up prototyping and delivery of vital life-saving medical equipment [3]. This includes 3D printing face shields, face masks, oxygen masks, goggles, and exam gloves. More advanced efforts have been conducted to produce low-cost ventilators and their parts and to share one ventilator between two to four patients using 3D printable modules.

In addition to general automation solutions, such as the above, that provide enormous benefit during a pandemic, there is a space for using specialized intelligent robotic and wearable systems to support and improve the functioning of the healthcare system. Such systems, whose utility during this health crisis will be discussed later, fall into one of the following categories in terms of *mechanical design*:

Fixed-base manipulators (or arms) are formed by a sequence of links attached together by joints. Fixed-base manipulators have one end fixed to the ground and the other end free to perform tasks in an environment dexterously.

Wheeled mobile robots are not fixated in a position and instead use a wheeled platform to move in an environment.

Flying mobile robots make another subset of mobile robots that fly instead of being earthbound. Aerial drones like quadcopters fall in this category.

Legged mobile robots have articulated legs that come in contact with the ground to provide locomotion. Legged robots span from **humanoid robots** (two-legged) to those inspired by multiple-legged arachnids.

Mobile manipulators consist of a fixed-base manipulator mounted on a wheeled, flying, or legged mobile robot. Mobile manipulators fuse the high mobility of a mobile robot and the dexterous operation ability of a fixed-base manipulator.

Wearable robots are human-worn devices that measure body signals and display information to the user through biofeedback to support, assist, or augment the capabilities of the user.

Exoskeleton robots are external mechanisms worn by humans for motor augmentation and strengthening the users' capabilities or to rehabilitate their lost abilities and function.

Below, we present some concrete examples of robotic systems that aid and complement healthcare in an effort to spark novel interdisciplinary initiatives between our medical, engineering, and science communities. This article also attempts to inform the public and policymakers about the real, practical, and life-saving benefits that can be had from incorporating robotics and automation technologies into the healthcare system. While automation is often depicted in popular culture as a force that eliminates jobs, now more than ever we need to consider its life-saving potentials as well. Finding the right balance and a science-based ethics-centred shift of culture towards more advanced use of

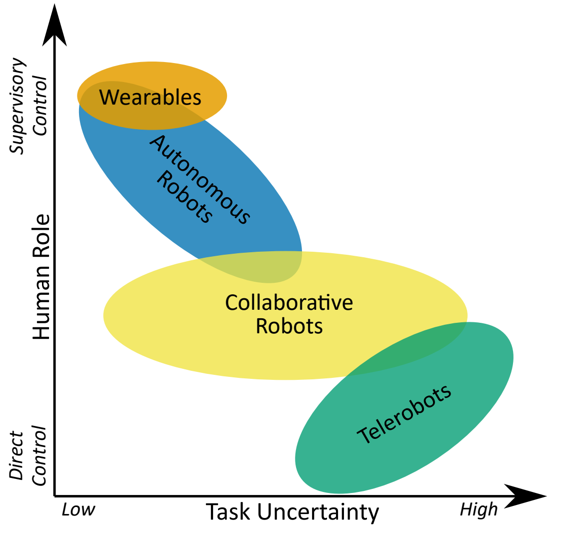

FIGURE 1 Comparison of different modalities of physical human-robot interaction in terms of human role versus task uncertainty.

technology requires information, dialogue, and collaboration. This article hopes to be a step in that direction.

4 | MEDICAL ROBOTIC, WEARABLE AND AUTONOMOUS SYSTEMS IN THE FIGHT AGAINST COVID-19

In times of deep health crises exacerbated by extreme socioeconomic pain such as during the novel coronavirus pandemic, medical robotic, wearable, and autonomous systems can be part of the solution. These systems can assist the healthcare system and defend public health in a number of ways. For instance, robots can be used to help prevent the spread of COVID-19 or assist in large-scale screening for it. Digital health solutions, including telehealth/telepresence technologies, can enable more effective and safer healthcare service delivery. Intelligent telehealth systems can significantly reduce the risk of infectious disease transmission to frontline healthcare workers by making it possible for them to triage, evaluate, monitor, and treat patients from a safe distance. A wheeled telepresence robot carrying a manipulator can be used for virtual face-to-face patient assessment and enables healthcare staff to perform diagnostic testing (e.g., taking a patient's temperature or swab samples) from a safe distance. Facilitating the curbside screening of patients while healthcare staff remain in a protected environment, telehealth technologies can reduce both the contact time between patients and frontline healthcare workers and the use of PPE during patient intake.

Another example of the potential use of robotic and autonomous systems is automating manual operations that are labour-intensive, time-consuming, and repetitive in order to reduce the burden on frontline healthcare workers. For instance, a mobile robot can be deployed to autonomously disinfect and clean healthcare facilities. Healthcare delivery can be made more efficient and safer through the application of materials handling and logistics robots, especially in the case of handling biological/infectious materials, distributing PPE and medications, and processing/sterilizing medical equipment. Robots can aid healthcare staff in treating hospitalized patients by enabling more effective healthcare delivery, particularly for those patients in isolation or critical-care.

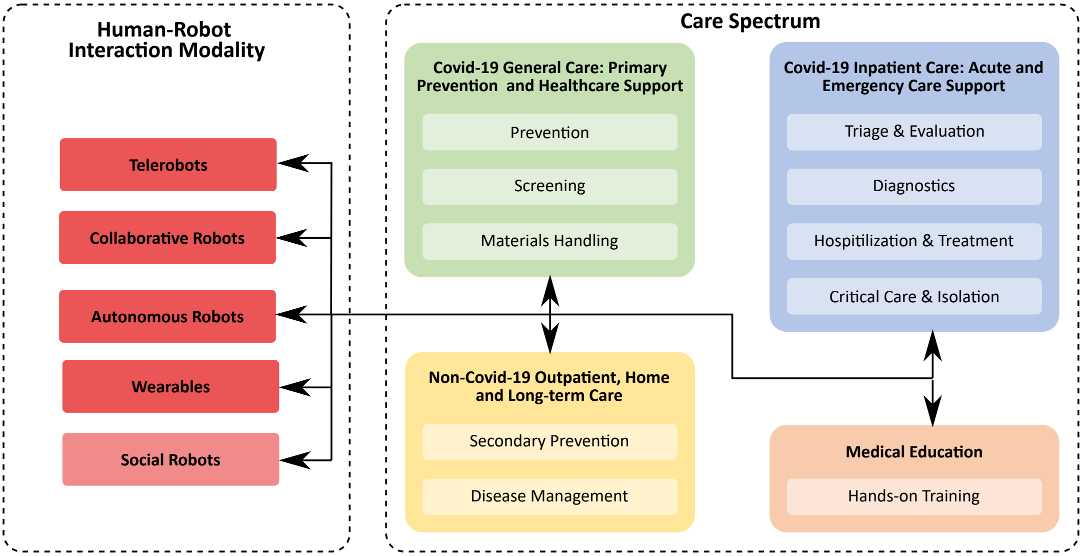

FIGURE 2 Overview of the spectrum of healthcare service delivery and how it intersects with various human-robot interaction (HRI) modalities.

In addition to the *mechanical design* of a robot, how it interacts with a human (e.g., a caregiver or a patient) matters when trying to systematically categorize various robotic solutions for the delivery of various healthcare services. The *modality of physical human-robot interaction* (HRI), where the human and the robot work in direct physical contact, depends on whether the robot is wearable, collaborative, teleoperated, or autonomous. Figure 1 shows how different modalities of physical HRI compare in terms of human role or input versus task or environment uncertainty [4]. Social human-robot interaction is about the robot acting and interacting in a way that supports the human's own actions and decisions.

The intersections between various human-robot interaction modalities and the spectrum of healthcare delivery are shown in Figure 2. Below, we only offer limited examples corresponding to a subset of possible robotic solutions existing at these intersections. The hope is that this starts a discussion and inspires others to quickly find new and innovative solutions that can be applied across the healthcare spectrum and using all possible modalities of human-robot interaction in the face of the current crisis.

4.1 | Telerobots

Telerobots, robotic systems with a user interface for their remote control by a human operator, offer the most obvious benefit in terms of assisting the healthcare system during the COVID-19 pandemic. Telerobotic systems can be designed to be completely sterilizable using commonly available liquid cleaning solutions so that the robot can be sprayed down and cleaned between interactions with various patients. Due to this ease of sterilization, telerobotic systems can be used during the intake and screening of patients.

Telerobotic systems already have a long history of use in healthcare settings. For instance, telerobotic systems for minimally invasive surgery have been commercially available for the past 20 years. The daVinci Surgical Robot made by Intuitive has obtained widespread adoption in hospitals all over the world. The patient-side manipulators of the daVinci are operated by a physician via a surgical console. While the surgical console is typically placed in the same operating room as the patient, with minimal change to current clinical practice, plastic sheeting or tents could be used to fully isolate the physician from patients with COVID-19. This allows the healthcare system to continue doing emergency minimally invasive surgeries and lower the risk to the physician during the pandemic.

Around the world, the supply of PPE has become limited with many healthcare systems asking workers to use PPE for long periods of time, re-use PPE, and even use makeshift PPE. These crisis-time practices increase the risk of infection to frontline healthcare workers and the risk of transferring infection from one patient to the next. Because of the true physical isolation that telerobots offer to the medical staff, they have great utility during a pandemic as they can reduce the quantity of PPE required for patient intake and treatment. For instance, telerobotic systems can allow a healthcare worker to use a robot arm to remotely, and with minimal PPE, operate and monitor medical equipment for patient care. A remote-controlled manipulator that can interact with the virtual buttons and dials on a touch screen can allow healthcare staff to interact with medical equipment in the intensive care unit without the need for PPE. This can be critical in ICUs where the risk of acquiring COVID-19 is particularly high for frontline healthcare workers.

For hospital or health center admission, a nurse or other frontline healthcare worker can remotely operate a wheeled mobile manipulator to evaluate intakes at the curbside while patients remain in their cars or before they step foot in the hospital. Using mobile manipulators, it is possible to use standard instruments, for instance, for measuring a patient's temperature, blood pressure, pulse, and blood oxygen without the need for a frontline worker to go near the patient. Such applications of telerobots would allow for more effective isolation of patients, for instance by redirecting patients likely to have COVID-19 to more protected screening areas and away from other critically ill or high-risk patients. The resulting reduction in risk to frontline workers and the reduction of PPE usage would be of immense value to the healthcare system.

Telerobotics can also be used to continue non-COVID-19 secondary healthcare operations both inside the hospital and in the community. One example would be using a teleoperated robot arm to perform ultrasound examinations for pregnant women. Here, the sterilizability of the telerobotic system significantly reduces the risk of the virus spreading to this high-risk group of patients. In fact, due to the physical separation afforded through teleoperation, the spread of the disease to sonographers or high-risk patients who need emergency ultrasound scans is controlled. Outside of the hospital, telerobotics can be applied to community care to continue routine healthcare activities such as rehabilitation or assistance. Telerehabilitation can be used to engage with patients at home and help them with their physical or cognitive rehabilitation activities [5, 6, 7]. Telerobotics-assisted telerehabilitation can allow high-risk groups such as stroke survivors to remain in isolation at home while receiving rehabilitation therapy through a distance.

4.2 | Collaborative Robots

Collaborative robotic systems are designed to work in close proximity with humans and are ideal when a human operator needs to physically interact with a robotic system for it to augment the human operator's abilities. A collaborative robot can have a handle on its manipulator so that it can be manually controlled by the user, e.g., for semi-autonomous ultrasound scanning of a patient's body [8]. While collaborative robots do not always offer the same isolation/protective benefits as telerobotic systems for a pandemic such as COVID-19, they have great utility when dealing with highly dynamic and changing tasks or environments. Another big benefit to using collaborative robots comes from the ability to continuously quantify and track the healthcare workers' interaction with a patient (e.g., through sensing their contact forces, positions, etc.) and use this information for either diagnostic/assessment purposes or to learn and memorize the human-human interaction for future medical student training.

Due to the ability to have the users directly interact with collaborative robots in a hands-on manner, these robotic systems can be applied as sterilizable physical mediators between a patient and a clinician, potentially reducing the need for PPE. Collaborative robots can also be used to reduce a healthcare worker's fatigue when doing a task, particularly strenuous or repetitive tasks — more about this later when we talk about exoskeletons. As a non-exoskeleton example, a collaborative manipulator can be used during high-volume swabbing of COVID-19 cases, where the manipulator would allow the healthcare worker to control the swabbing process from a more ergonomic posture, reducing fatigue and strain, and from a larger distance than normally possible. This might help reduce the need to change PPE between patients.

What makes collaborative robots even more interesting is that there exists technology for the robot to learn from demonstrations provided by a healthcare worker how to execute motions or force exertions to achieve a given task. Utilizing Learning-from-Demonstration (LfD) techniques, a collaborative robotic system can be trained and retrained through hands-on manipulation of the robot commonly known as kinesthetic teaching by the user. For instance, LfD can be used to teach a robot how to replicate a physiotherapist's intervention for a patient with disability so that the patient can engage in repetitive rehabilitation exercises [6, 7, 9, 10]. Robot learning technologies offer an intuitive way for non-programmers such as healthcare workers to intuitively and quickly program robots to perform new tasks, e.g., taking a swab sample, with negligible downtime. This kinesthetic teaching paradigm also allows for collaborative robotic systems to be quickly redeployed to do different tasks as the healthcare system determines where to automate certain functions. For instance, a collaborative robot initially trained to assist a technician in lab diagnostic procedures can be quickly reprogrammed by anyone to distribute PPE using LfD algorithms.

The adaptability and hands-on teachability of collaborative robots have caused their wide-spread deployment for factory automation as is the case with Rethink Robotics' Baxter [11] and Sawyer robots among others. Outside of healthcare, having robots that can be quickly trained and deployed can be used for manufacturing and production to, for instance, temporarily take over the role of a worker who is isolated or has fallen ill to keep the production steady.

Exoskeletons are another example of robotic systems that help ensure the continuity of non-COVID-19 outpatient care during the pandemic. As wearable robotic systems, exoskeletons are gaining interest in various technological domains, including medical robotics. Due to the tight physical coupling of an exoskeleton with the human body, it is considered a collaborative robot. Lower-limb exoskeletons are able to provide gait assistance to people with disabilities such as stroke or spinal cord injury such that they become less dependent on caregivers when they need to keep a physical distance. Upper-limb exoskeletons can be used during the physiotherapy of those with upper-arm injuries so that the therapist can work with the patient from a safe distance. Also, upper-limb and lower-limb exoskeletons can physically assist material movers, freight workers, construction workers, and warehouse staff who routinely face high risks of overexertion in the solo performance of tasks that require more than one person. In other words, an exoskeleton allows for the solo performance of physically demanding tasks where physical distancing between workers needs to be exercised. For dealing with the high number of patients during this pandemic, an exoskeleton can be used to partially support the weight of healthcare workers and reduce their fatigue when they need to stand for long hours. Also, exoskeletons can help healthcare workers in physically demanding tasks such as moving patients between beds, changing the patients' clothing and bedsheets, and cleaning the patients.

Robotic task simulators are yet another application of collaborative robotics for continuing the medical education or training the healthcare staff remotely. Collaborative robots with augmented reality (AR) technology have been making their way into the medical field in recent years. These robotic trainers/simulators have been shown to increase the motivation of users, e.g., medical students in need of hands-on training, and keep them engaged through possible gamification of target activities. The role of 3D AR displays is to immerse the user in a virtual environment of a given task. Then, the collaborative robot is integrated for simulating the physical dynamics of the task (i.e., haptic interaction) for the user. The result is a task simulator that integrates both an AR display to provide reconstructed visual feedback and a collaborative robot to provide reconstructed haptic feedback of the simulated task to the user.

Medical simulators can replicate tasks from simple ablation to highly complex diagnostic procedures. Various dental, laparoscopic, and endovascular training simulators allow for remotely delivering education and training to medical students. Having a robotic system allows for masking the task parameters from the trainee when needed and keeping track of the user's performance for quantitative assessments and performance scoring. Specifically, within the COVID-19 pandemic, a simulator can allow for training healthcare workers on needed techniques or procedures. During the pandemic, there has been a large number of false-negative results for swab tests due to improper swabbing techniques such as not swabbing far enough in the back of the nose or throat. Using a simulator, a trainee can be better trained to properly swab the necessary area through realistic force feedback and AR display technology.

Robotics-AR simulators can also be used for rehabilitation and assessment of non-COVID-19 patients in home care or long-term care so that they continue to receive the care they need. For instance, for occupational rehabilitation of workers who have sustained injuries at the workplace, the injured worker needs to engage in functional tasks that simulate the workplace environment for a Functional Capacity Evaluation (FCE) that assesses a worker's abilities and performance. In this situation, a robot-AR task simulator is highly beneficial for simulating various workplace tasks for both FCE and to help the injured worker regain their functional capabilities and return to employment [9].

4.3 | Autonomous Robots

Autonomous robotic systems are capable of undertaking actions independently with minimal or no interaction with a human operator. Perhaps the greatest example of autonomous wheeled mobile systems that have been deployed during the COVID-19 pandemic is UV sterilization robots [12]. While sterilization is one aspect of cleaning healthcare facilities, wheeled mobile manipulators can be used to remove bedding and other contaminated materials from hospital rooms before autonomously disinfecting the equipment. A wheeled mobile robot that moves between patients' rooms or treatment areas can be used to autonomously record patient vital sign read-outs and, with the addition of a manipulator, can be used to interact with medical equipment, reducing healthcare workers' contact with contaminated surfaces. Wheeled mobile robots, similar to self-driving cars, can be used for logistics purposes and autonomously move materials, equipment, medications, PPE, or other supplies around a hospital as required.

4.4 | Wearables

Wearable technology refers to smart body-worn electronic devices for measuring, analyzing, and transmitting information. The information can be, for instance, body signals related to vital signs and physical activity. Wearable technologies can also provide information to the wearer through display technology or vibrotactile feedback. Common examples of consumer wearables include activity and vitals trackers that encourage people to exercise and provide them with real-time feedback on exercise effectiveness. Wearable technology for healthcare monitoring of biometric activity such as heart rate (ECG), brainwaves (EEG), and muscle bio-signals (EMG) are commercially available and already used with increasing frequency to diagnose various disorders outside of the hospital or to monitor and track patient recovery from a distance [13].

Augmented/virtual reality head-mounted displays are another example of wearable technologies. While perhaps the best-known use of virtual reality technologies is in consumer video games, during the coronavirus pandemic the technology can be adapted to help in public health, aid medical professionals, and provide immersive platforms for telehealth and telerobotics control. Virtual reality, and to a lesser extent augmented reality technologies, are commercially available off-the-shelf consumer-grade products. Healthcare workers can use virtual and augmented reality technologies to enable intuitive collaboration for remote diagnosis or treatment planning. As an example, a virtual reality environment can bring together several doctors to view the result of a CT scan and allows senior physicians to safely provide their expertise and experience even when they are in isolation.

Aside from healthcare workers, there is a direct benefit to the public from leveraging virtual and augmented reality technologies. Collaborating and interacting virtually can lessen the negative effects of social isolation caused by the novel coronavirus pandemic. For instance, they allow teachers to use avatars to teach school children and allow children to engage in virtual playtimes with their peers.

Lastly, virtual/augmented reality can also be used as an interface for remotely operated telerobotic systems, allowing one to intuitively move a wheeled telepresence robot to perform remote diagnostics or equipment operation. Such a remotely-operated robotic system with virtual/augmented reality visualization may be the only practical way for healthcare workers to keep track of patient needs and vital signs in makeshift healthcare environments such as gyms or tents, which are not configured for remote readouts.

4.5 | Social Robots

Social robots are able to interact and communicate with humans and their surrounding environment. Social robots have been constructed in a range of form factors from pet-like toys (e.g., Paro) to humanoids (e.g., Sophia). Different types of sensors and actuators can be incorporated into social robots to make the interaction more effective. For instance, social robots resembling human heads can speak and interact with users while measuring the user's mood, temperature, stress, and vital signs via various embedded sensors.

Social robots can play a large role in dealing with the mental health and well-being of those in quarantine or isolation by making them less lonely and more socially engaged. They can motivate and engage people and increase their quantity/quality of social interaction while maintaining quarantines. The focus of social robotics research has traditionally been on robots for elderly care and children with disabilities. This population has been particularly affected during the current pandemic as many seniors, group, and long-term care homes have stopped allowing family members to visit. This population can see immediate benefits from the use of social robotics. With the current mass quarantines, social robots may also be used to ease the strain and negative mental health effects of social isolation for people of all ages and physical/mental abilities.

Various forms of robotics systems have been used on a social interaction level during the coronavirus pandemic. During the Wuhan lockdown, Chinese authorities deployed drone systems to detect people who had left the isolation of their houses and employed loudspeakers to encourage them to return home. While implementing such approaches requires care and accounting for cultural differences across different countries, the mere ability to remotely monitor the state of physical distancing or quarantine in a community might prove beneficial in detecting the next hot spots.

5 | CONCLUDING REMARKS

The remarkable speed and severity of the coronavirus pandemic have been without parallel in the modern age. While this is a time of great tragedy, it has also shown the importance, ingenuity, and resilience of healthcare and essential workers worldwide. This tragedy should also serve as a catalyst to prompt discussions about innovative uses of technology, reconsidering the paradigms of how healthcare is delivered, and understanding the importance of funding innovation both privately and publicly well in advance of a crisis. Above, we proposed many areas where robotic systems can be immediately used to aid the healthcare system, healthcare workers, and society during the current pandemic. These are simply some examples of how the medical, engineering, and science communities can come together to support and complement healthcare. We hope to have encouraged this interdisciplinary dialog, so that together we can find ethical, practical, and beneficial solutions to effectively tackle this and similar crises.

This crisis has prompted a movement to freely share technical designs and collaborate across borders allowing the global community to benefit from the wisdom of the crowd in real-time. This open-source mentality, while long practiced before the health crisis, has been rapidly adopted by a number of companies freely distributing their once-proprietary designs. For instance, in an effort to save lives by circumventing production and supply chain limitations, Medtronic is sharing the design specifications and the software code of a ventilator model with other companies that can produce them. This spirit of collaboration and innovation has the potential to profoundly affect the way engineering and scientific research is done in the future [14]; never before in history have so many international researchers joined efforts together on a single topic of research.

Medical robotics technology has come a long way, but this research takes time and investment before it can be widely deployed during a crisis. Immediate investment in this technology is a good first step in making healthcare delivery safer and more efficient for patients and healthcare workers. When we emerge out of this pandemic, these new technologies and paradigm changes deserve continued attention, research, and implementation. There needs to be a recognition that wearable and robotic technologies combined with machine intelligence and autonomy have excellent potential for meeting the healthcare systems need for safer, more robust, and more efficient delivery of care to everyone including both COVID-19 patients and other patients.

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Conflict of Interest

The authors declare no conflict of interest.

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