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## REVIEW ARTICLE

# Transforming the Medical Landscape: Applications of Robotics and Artificial Intelligence in Combating Infectious Diseases

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### Abstract

Robots have been developed for use in a variety of settings over the past decade. Examples of applications include rehabilitation and mobility, surgery, telepresence, and social assistance. These technological innovations have incredible potential in helping combat the spread of infectious diseases around the world. In this paper, the applications of robotics in diagnostics and surveillance, healthcare delivery, vaccine development, and research in regard to infectious diseases will be discussed. Recent advancements in robotics and artificial intelligence (AI) allow robots to perform more functions than ever before including processing real time data and making public health recommendations, detecting and tracking the presence of pathogens via robotic biosensors, and assisting in image-based diagnostics. In the healthcare setting, robots are able to assist in sanitation, hospitality, and the delivery of food and medications to patients. Robots have also assisted in the development and mass-manufacturing of vaccines during outbreaks such as the recent COVID-19 pandemic. However, ethical considerations and technological limitations may ultimately determine how well robotics is received among the general public and medical community. The largest of these concerns pertain to privacy and data security, quality of care, and resource allocation. It is crucial for researchers, medical professionals, and public health officials to keep such aspects in mind as they continue to innovate and transform the medical landscape.

**Keywords:** Infectious Diseases, Robotics, Artificial Intelligence, Inventions, Developing Countries

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### Introduction

Modern robots are defined by their ability to be dynamic and autonomous to a certain degree as they use artificial intelligence (AI) to make decisions or perform particular actions such as receiving input from their surroundings, processing it, and responding in a meaningful manner. These characteristics make modern robots one of the most advanced technological innovations in recent decades and allow them to depart from traditional machinery.

The field of biomedical engineering and medical robotics is promising due to the expanse of potential applications in the healthcare setting, especially during infectious disease outbreaks [1]. During the COVID-19 pandemic between 2019 and 2021, as the number of cases rose, the cumulative number of instances of using robots around the world for various purposes including public safety, clinical care, and laboratory and supply chain automation correspondingly increased [2]. At a time when the lives of both patients and medical professionals are at risk, health infrastructure is stressed beyond capacity, and quick medical response is needed to treat patients and prevent further spread, robots can work hand in hand with doctors, researchers, and public health officials to curb outbreaks.

### The Nature of Infectious Diseases

Infectious diseases have impacted communities across the world for as long as human history. These types of diseases, characterized by their pathogens' transmissible nature, kill millions of people every year and leave many more disabled [3]. They also tend to disproportionately affect those in less developed countries and of low socioeconomic status [3].

Identifying potential reservoirs of infectious agents can help determine required mitigation efforts and identify potential opportunities for robotic applications. Diseases in which humans are the only reservoirs, such as smallpox, can be more easily eradicated due to the specificity [3]. On the other hand, environmental reservoirs such as bodies of water and soil can be more difficult to contain [3]. For instance, *Clostridium tetani* can cause tetanus even when surviving in soil for years [3]. Other infectious diseases such as Human immunodeficiency virus (HIV) may originate from animals then evolve to only spread between humans [3].

Approximately 60% of infectious diseases are due to zoonotic transmission or in other words transmission from animals to humans [3, 4, 5]. Pandemics have greater chances of originating in regions of the world which have high interaction with wildlife or livestock. For instance, Ebola resulted from

the transmission of virus from infected primates to humans who consumed their meat [4, 6]. From the origin of a pandemic, the number of people impacted is largely determined by the preparedness of the origin country and how well the disease is able to be contained. However, when analyzing countries based on their preparedness index, it is shown that the regions which are the most vulnerable are the least prepared [4]. As discussed later in this paper, resource allocation is therefore critical in ensuring global health, stability, and wellbeing.

## Diagnostics and Surveillance

The ability to quickly diagnose patients and track the spread of infectious diseases in populations can play a pivotal role combatting outbreaks. AI-assisted technologies have the potential to oversee these processes and generate public health recommendations based on real time data. For instance, during the COVID-19 pandemic, the Health Service Executive and the Health Protection Surveillance Centre (HSE-HPSC) in Ireland created a surveillance robot named Computerized Infectious Disease Reporting (CIDR) which processed laboratory records, managed contact tracing data, and generated notifications accordingly [7]. While humans took an average of 26 minutes for each case, CIDR took less than 4 minutes and was able to run for 22 hours each day, significantly easing the stress on the nation's healthcare system and its workers in the pandemic environment [7]. Medical facilities have also developed robots to partially automate processes involved in analyzing COVID-19 tests [8]. In one instance, processing capabilities increased by 66% [8]. In this sense, the use of robots can maximize the efficiency and speed at which data can be processed and applied in the health setting.

Another area of exploration is the use of robotic biosensors to monitor environmental conditions in affected communities. Biosensors function by essentially detecting target molecules via specialized receptors and then using transducers to send electrochemical, optical, or microgravimetric signals to processing units. They may be able to test the air or water for traces of pathogens and infectious diseases and alert public health officials accordingly using AI. A variety of biosensors have currently been developed including those which are enzyme-based, whole cell-based, antibody-based, and DNA/Aptamer-based. For instance, researchers from Germany and the Czech Republic were able to create a microfluidic biosensor that could detect bacteria (*Pseudomonas taiwanensis* VLB120 and *Escherichia coli* DH5α) in drinking water using surface-enhanced Raman spectrometry (SERS), a method that involves adding nanostructured material such as silver to the solution for binding with target molecules [9]. They then filtered the water sample using nanoporous membranes and electrodriven flow [9].

AI-assisted technologies can also assist in image-based diagnostics. For instance, a team focusing on differentiating diagnosis between tuberculosis (TB) and pneumonia created a Support Vector Machine (SVM) and artificial neural network (ANN) which were able to reach 99.6% accuracy along with similar rates of precision and specificity [10]. The researchers discussed multiple approaches based on a combination of VGG16, ResNet18, SVM, and ANN [10]. First, a 5x5 pixel average filter was used to reduce noise in the initial images by averaging the values for 24 adjacent pixels [10]. A Laplacian filter was also applied to a copy of the initial set to enhance the contrast and better identify the region of interest (ROI) [10]. Then, the two sets of images were combined and processed through VGG16 and ResNet18 [10]. The resulting high dimensional features were reduced using principal component analysis (PCA) and the remaining selected features in the data set were extracted and processed through SVM or ANN depending on the approach [10]. One of the challenges in creating such AI is the need for a large, representative data set. It may be difficult to obtain a sufficient number of images in the case of a newly emerging infectious disease. Medical professionals can thus also utilize Human-In-The-Loop (HITL) AI to develop its understanding of a particular data set and better process incoming information. Human interaction and consistent feedback submitted to AI can be particularly useful when there is a limited data set such as in the case of an emerging disease, as it can increase confidence levels and accuracy for predictions beyond what AI might be able to extract or determine from the data.

Robots have various applications in laboratory settings. They have been instrumental in the creation of vaccines for various diseases, especially in terms of research, development, and manufacturing. For instance, utilizing robotics for microfluidics can improve efficiency and decrease chances of contamination or human error [11]. Such robotic liquid handling has been implemented through single-channel and multi-channel pipet arms, which can measure specific volumes in order to produce accurate results [11]. Droplet generators such as the DG8 NIB are even able to produce 0.7 nL droplets [12].

Robotics have also allowed for improved point-of-care testing options as opposed to depending on large, expensive, and distant laboratories for analysis which may delay response times and require additional sample transportation costs in less developed areas [13]. For instance, researchers have been crafting portable microfluidic devices for testing for HIV [13]. In order to overcome the time-consuming processes involved in sample preparation, reagents were prepackaged and used by automated detection systems to perform the necessary procedures [13]. Similar devices created for detecting Zika virus were

able to take only up to 40 minutes whereas conventional techniques such as benchtop PCR would have taken 1-3 hours just for sample preparation itself [13, 14].

## Healthcare Delivery

Using robots for treating patients during infectious disease outbreaks can increase the chances of containment and help protect medical professionals who fight in the frontlines. Researchers modeled a geriatric unit and conducted five different scenarios where a pathogen spreads due to close personal contact [15]. First, a control scenario was established where no robots were utilized [15]. Second, the top five high-risk nurses were replaced with robots [15]. Third, the top three high-risk nurses and two random doctors were replaced [15]. Fourth, all the medical staff were replaced with robots [15]. 100 trials were performed and the probabilities of containment for each scenario were averaged [15]. When compared with the control, the scenarios which incorporated robots had a 22% chance of containment whereas the control had a 10% chance [15]. In other words, the probability increased by 110% and significantly decreased the number of active infections, demonstrating the potential benefits of utilizing robots [15].

A variety of robots have been developed to assist in the healthcare setting. One of the most important uses pertains to sanitation. Robots that disinfect spaces and keep them pathogen-free can help contain the spread of infectious diseases. For instance, UV-bot is an autonomous robot that uses ultraviolet light to sanitize hospital premises for COVID-19 [16]. Its researchers used an A\* algorithm to maximize speed and efficiency by calculating the shortest possible distances to navigate and cleanse the room [17]. The Raspberry Pi 4 was utilized along with an infrared sensor for detecting human motion [17]. A three-dimensional simulation was also performed using a model which showed that the robot had an error rate of 3-5% in detecting obstacles or edges [17]. Other robots such as iMap9 can also clean surfaces using a solution containing sodium hypochlorite [16]. The utilization of such robots can decrease human interaction with pathogens [16].

During an infectious disease outbreak, hospital staff and resources may also be strained. Thus, hospitality robots can fill in for roles such as receptionists for appointments and questions and servers for medication and food [16]. Such robots can handle their share of tasks while human workers can complete the more irreplaceable duties [16]. For instance, Sona 2.5 has the capability for contactless delivery of food and medicine as well as the monitoring of patients' body temperatures [16]. Similar robots such as KARMI-BOT and Co-bot also perform delivery services in order to reduce the chances of pathogen spread [16].

During the COVID-19 pandemic, various telehealthcare technologies were used in order to treat patients without direct contact. For instance, cardiopulmonary function was assessed in a COVID-19 patient using an ultrasound robotically operated 1,479 kilometers away using the MGIUS-R3 robotic ultrasound system [18]. Similarly, an echography examination on the patient's lungs, heart, and vascular system was performed 700 kilometers away [18]. Researchers are also in the process of designing a robot that can utilize deep convolutional neural networks to autonomously locate and insert needles into patients' blood vessels as opposed to requiring human interaction [18].

## Engineering Challenges and Approaches to Outbreaks

The medical research community has been working on various fronts to engineer robots for collecting data, predicting outbreaks, and treating patients. As the world population rises, global climate patterns change, and global mobility and interconnectedness increases, the risk for an epidemic or pandemic likewise significantly increases. Thus, it is critical for health infrastructure to keep up with the demands of the evolving modern world.

There are three main types of data that should be collected to help manage infectious disease scenarios: agent detection data, agent characterization data, and hazard characterization data [19]. Agent detection data refers to the identification of sources, reservoirs, and hosts as well as the pathogen's distribution and exposure level in the community [19]. Agent characterization data refers to the biological characteristics that are unique to the pathogen and its mode of transmission [19]. Hazard characterization data refers to health effects of the pathogen, which populations are at the most risk, and effective efforts of controlling spread such as social distancing [19]. Collecting these three types of data should be a priority, as they determine how public health officials can plan and combat a particular outbreak [19]. Researchers should focus on engineering devices that could gather such data in a timely manner, be financially accessible to less developed countries, and use more widely available materials for manufacturing [19].

Researchers are engineering robots for infectious disease treatment as well. For example, robots could potentially use cold atmospheric plasma (CAP) to treat lungs infected with COVID-19 [20]. CAP, containing a combination of reactive oxygen and nitrogen species which can trigger a natural immunogenic response, could also be delivered to target regions of the body using nanorobots [20]. These nanorobots can be manufactured using techniques such as physical vapor deposition, a process in which metals are converted into a gaseous form in a vacuum for deposition onto

thin surfaces to construct nanofilms [21]. Researchers have also developed various mechanisms for chemical, physical, and biological nanorobot propulsion [21]. Chemical compounds such as  $H_2O_2$  can be used as fuel by carrying out chemical reactions which produce bubbles for movement [21]. External magnetic fields or light sources can be used to control magnetic or photoreceptive nanorobots respectively [21]. Finally, microbes such as *E. coli* have even been used as propellers for magnetically modified red blood cells for targeted drug delivery [21]. AI can be particularly helpful when managing a large quantity of devices at such a small scale. If nanorobots are brought into clinical care—especially in resource-limited settings—AI will ease the learning curve necessary for operating these tools and increase accessibility.

As researchers work towards these goals, there are some key engineering challenges to overcome in order to be able to use novel technology in less developed countries. First, robotic processes have to be miniaturized and simplified in order to be affordable and portable to rural locations. These efforts must also not compromise the accuracy or functionality of the robots. Second, if they are to move around medical facilities or local hotspots, they ought to be designed to dynamically navigate uneven surfaces or rough terrain. Third, and perhaps most importantly, they must be designed to have the least power consumption in order to be feasible in resource-limited settings. Many afflicted regions may not have a consistent power supply, and robotic procedures should not be halted especially when performing for instance diagnostic sampling and testing. Fourth, harsh environmental conditions such as heat may impact the performance of the robots and damage the mechanical parts which may be difficult or expensive to replace. The maintenance of robots in such settings may be particularly challenging. In this sense, the more adaptable and dynamic the technology, the more promising it can be.

## **Ethical Considerations and Technological Limitations**

When considering the use of robots in the medical field, three main concerns arise: privacy and data security, quality of care, and resource allocation.

Robots must have access to a vast collection of patient records in order to perform the functions detailed previously such as processing real time data to make public health recommendations, assisting in image-based diagnostics, and delivering medication and food to patients. This wealth of information should be highly protected with patients' privacy in mind. While policies like the Health Insurance Portability and Accountability Act (HIPAA) may protect patients in the United States, many developing countries have weaker protections and security infrastructure to safeguard its data [22]. For instance,

South Korea had limited privacy controls when using patient data for public COVID-19 contact tracing and this resulted in stigmatization and fear [22].

One of the most important aspects of practicing medicine is empathy. When medical professionals incorporate AI-assisted technologies such as modern robots into the workplace, how much of that empathy remains and how would it affect the patient experience? As humanity ventures into a future where robots become increasingly normalized in medical care, it is essential to not compromise patients' mental wellbeing and potentially their physical health. When transitioning from a human workforce to an integrated alternative, it is therefore more important than ever for medical staff to be vigilant and ensure that their patients are receiving proper holistic care.

Less developed countries suffer from infectious diseases the most [23]. Communicable conditions such as tuberculosis impact large populations and the local medical professionals are often the ones who need advanced equipment to aid their efforts for treatment and containment [23]. However, the health systems in most of these countries cannot afford potential technologies. Resource allocation towards regions who face significantly higher levels of communicable diseases not only benefits the people of those regions, but it also helps protect global health and stability by increasing the likelihood of containment. If future outbreaks are managed with novel robotics, communities may be able to prevent a potential epidemic or even pandemic.

## **Regulatory and Legal Considerations**

The evolution of robotics along with AI prompts the evolution of regulatory laws as well. When robots are given a degree of autonomy, they need to be held accountable for their actions. Thus, in order to create specific regulations based on their capabilities, researchers established six levels of autonomy for medical robots [24]. Level 0 refers to robots having no autonomy where the robot is only able to follow particular commands [24]. Level 1 refers to robots which are able to guide or assist users using for instance virtual fixtures but cannot make decisions [24]. Level 2 refers to robots which have the autonomy to make decisions while completing a given task [24]. For instance, the user may select a location and assign the robot to suture the patient autonomously as it is monitored [24]. Level 3 refers to robots which have conditional autonomy and can carry out tasks without significant oversight such as automatically-adjusting prosthetics [24, 25]. Level 4 refers to robots which have the autonomy to make medical decisions while being supervised, and Level 5 refers to robots which have complete autonomy over decisions and actions [24]. Though researchers have not developed a Level 5 medical robot yet, it is important to establish the



expectations and required regulations beforehand [24].

Without proper oversight, the higher the level of autonomy, the more dangerous its decisions can potentially be [24]. In this sense, regulations ought to increase as the categorized level of the robot increases [24]. Robots with higher levels of autonomy also ought to receive oversight via the requiring of licenses if the robot is capable of making health recommendations and decisions; because its role overlaps with that of a certified medical professional in such scenarios, the robot must be treated as both a medical device and a medical practitioner [24]. Its involvement in diagnosing patients and providing treatments ought to be closely monitored by the medical community [24]. Because they can have access to research and information published around the world at any recent point in time, robots may also be more updated than traditional doctors [24]. Yet, the medical community should remain cautious and proceed slowly as it treads on uncharted territory.

## Conclusion

The applications of robots are virtually endless, especially for infectious diseases. In the future, robots may hopefully be used to run mass testing or screening stations, deliver medication, work in field hospitals, automatically sanitize public spaces, and enforce measures such as wearing masks or social distancing. Doing so can limit the potential interactions between patients and medical professionals directly, thus decreasing the chances of infection and spread.

However, at the same time, it is important to keep empathy and humanity in mind. Medical professionals still need to connect with their patients and should not allow the digital setting to create a barrier in communication and understanding. While moving towards an increasingly tech-integrated medical field, it is essential to not leave behind groups who may be unfamiliar or hesitant such as the elderly. Digital usage and literacy should be taught in order to maximize the patient experience and help connect patients to quality medical care. Both providers and patients should be careful regarding security breaches and compromises in personal health information. Looking into the future, artificial intelligence, like the invention of the internet, has enormous potential in transforming healthcare and the delivery of treatment. Perhaps one day, taking a picture of a medical condition via an app can generate an accurate diagnosis which can then be further verified by a doctor. Regardless, as humanity navigates the digital future, medical professionals and providers ought to keep the patient experience as their number one priority.

In addition, as mentioned before, issues such as the unequal access to financial and material resources

between developed and developing countries are sure to play a key role in determining the future of pandemic preparedness and global security. Investment and partnerships are promising solutions as researchers work on tackling challenges such as miniaturization and simplification, dynamic navigation, environmental conditions, and power consumption. Entities such as the World Health Organization ought to encourage collaboration and the exchange of knowledge without barriers. Open-source initiatives where information and data can be freely shared should be promoted. One of the largest factors holding innovation back is perhaps gatekeeping and looking for profits. Governments should take initiative and offer incentives for sharing research and collaborating instead of only awarding those who produce the desired results such as creating a vaccine. When developing novel robotic technology, developed nations should make it a priority to make it accessible to those in less developed nations. Governments should also partner with private companies to foster innovative solutions to problems such as power management for medical robots in resource-limited settings.

A significant obstacle to international collaboration is government instability in some less developed countries. Issues such as corruption may prevent quality care from reaching vulnerable populations such as those in rural regions. Even in a developed country like the United States, billions of dollars are lost every single year as a result of corruption and fraud in the healthcare system. Counterfeit medications and devices are also being created and circulated in the market, especially in less developed regions such as Africa. Finally, war and political upheaval can make collaboration across borders difficult. Medical equipment can be damaged during transportation and distribution. Local divisions in the community based on factors such as caste or tribe can result in minority groups not having equal access to these novel technologies. In this sense, the particular location's circumstances greatly influence how well robotic solutions are received and whether they can maximize their impact or reach their full potential, especially in the context of infectious diseases.

Nevertheless, it is more important than ever before to invest in robotic innovation and technological advancement. The recent COVID-19 pandemic has evidently shown that preparedness is key in combating potential outbreaks. Expanding applications in the aforementioned sectors such as diagnostics and surveillance, healthcare delivery, research, and manufacturing is sure to produce valuable outcomes and promote global health and wellbeing around the world.

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