Chapter

Service Robots in Healthcare Settings

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Abstract

Robots will play a part in all aspects of healthcare. The presence of service robots in healthcare demands special attention, whether it is in the automation of menial labour, prescription distribution, or offering comfort. In this chapter, we examine the several applications of healthcare-oriented robots in the acute, ambulatory and at-home settings. We discuss the role of robotics in reducing environmental dangers, as well as at the patient's bedside and in the operating room, in the acute setting. We examine how robotics can protect and scale up healthcare services in the ambulatory setting. Finally, in the at-home scenario, we look at how robots can be employed for both rural/remote healthcare delivery and home-based care. In addition to assessing the current state of robotics at the interface of healthcare delivery, we describe critical problems for the future where such technology will be ubiquitous. Patients, health care workers, institutions, insurance companies, and governments will realize that service robots will deliver significant benefits in the future in terms of leverage and cost savings, while maintaining or improving access, equity, and high-quality health care.

Keywords: Healthcare, acute care, ambulatory care, surgical robotics, at-home robotics

1. Introduction

With the introduction of robots into industrial domains, the exploration of remote controlled, semi-autonomous and fully autonomous surface robots within the field of healthcare is an area of increasing interest. Robotics has been considered across the major verticals of the healthcare continuum of prevention, screening, diagnosis, treatment, and homecare [1]. However, service robots could potentially fill the roles of typical industrial robots in the management of menial or laborious tasks such as supply chain management and logistics, stocking and inventory control, back-end support as well as delivery within the context of patient care. For example, consider delivery of medication or supplies [2]. With the use of robotics such as autonomous vehicle or drone fleets, a routine one-to-one delivery could be simplified; a high priority urgent delivery during acute care events could be made feasible; or broader community-based delivery could be made autonomous for an entire region [2]. Service robots in healthcare can also serve in direct patient interaction roles including as direct assistance to healthcare workers such as nurses, physicians, imaging technicians, and more [3–5]. In a patient-centered view, service robots may serve the role of comfort care or as personal assistance to the patient for mobilization, feeding or activities of daily life [6, 7]. The breadth of applications is vast. This chapter focuses on the application of service robots at the interface of health care delivery, highlighting advances in acute care settings, such as the hospital or surgical settings; in ambulatory settings such as clinics; and in at-home settings where we consider comfort and health. The detailed discussion of supply-chain and logistics-based service robotics are left to other chapters to discuss.

2. Service robots in acute care settings

Acute care refers to the delivery of short-term diagnosis and treatment of a patient for a medical condition. These settings may require an emergency department visits where patients are rapidly assessed and provided with initial treatment, an admission into hospitals whereby patients are overseen by multidisciplinary healthcare workers, a surgical operation including the post-operative recovery, and any number of related services (imaging or laboratory services for example) required to provide optimal diagnosis and treatment.

The first application of robotics in this setting is with regards to environmental hazards. This mimics the notion of industrial robotics to protect workers from workplace hazards. As underscored by the global COVID-19 pandemic, there is heightened interest in the use of robotics to protect valued healthcare workers and patients from dangerous environmental scenarios including preventable infections, ionizing radiation, or combative and violent scenarios. As a key example, the routine care of patients infected with COVID-19 requires significant investment of time and resources on the healthcare delivery system, while continuing to put healthcare workers at risk, and leading to reallocation of resources and cumbersome delivery of patientcare. For two examples of robots created in response to this pandemic, we refer to two companies based in Denmark. First, consider how the nasopharyngeal swab, required for collection of respiratory mucosa to diagnosis COVID-19, inherently places the worker performing the swab at risk. Lifeline Robotics (Odense, Denmark) developed the CAREEBO system, the first of its kind to perform a fully automatic swab analysis [8]. The robotic system is designed to interact with patients and perform the swab itself, obviating the need for a healthcare worker to be in proximity with a potentially infectious individual [8]. Likewise, disinfection and sterilization of the surrounding environment is a key step in the preventing infectious disease transmission. Existing procedures still rely on human staff to perform the cleaning, which may in turn be tedious, costly, and time consuming as well as an avoidable exposure. Towards prevention in hospital settings, ultraviolet light has been utilized in a touchless manner through mobile service robotics. This approach has been demonstrated superior results to manual cleaning when evaluating the number of microbes as well as reducing infection [9]. Commercial offerings exist, such as UVD Robots (Odense, Denmark) designed to disinfect patient wards and operating rooms in between admissions [10].

In a similar fashion, despite standard of care barrier methods, interventional radiologists and radiology technicians who work with and nearby to ionizing radiation continue to suffer increased rates of malignancies as compared to the general population. Mitigating the exposure risk for these individuals directly relates to their safety. Enhanced robotic imaging instrumentation may be the avenue to achieve this. However, to the best of our knowledge, there is not yet a fully autonomous commercial imaging system available for clinical usage. Researchers have explored the notion of a robotic imaging instrumentation. As an example, Haliburton *et al.* towards a service robot for a fluoroscopy machine by demonstrating their tracking system called On-board Position Tracking for Intraoperative X-rays (OPTIX), achieved clinically relevant accuracies through the addition of a single camera [11]. The end goal for OPTIX was to reduce the number of fluoroscopic images required in an operation [11]. This system is one step towards semi-autonomous and fully autonomous robotic systems. Environmental safety, as demonstrated by infection risk and ionizing radiation, can be ameliorated using service robots. In doing so, we consequently mitigated the overhead of anxiety and stress related to working in these potentially hazardous environments.

Moving beyond environment, service robots have a role to play at the patient's bedside. In the most literal example, service robots can assist patients with physical limitations such as reduced physical ability or a bariatric patient in mobility. For these patients, service robots enable patients to have fundamental needs such as having a robotic arm to mitigate the loss of mobility in one's natural arm. Japanese researchers at the RIKEN-TRI Collaboration Center for Human-Interactive Robot Research developed the world's first nursing-care robotic system that can transfer a patient from a bed to wheelchair, and vice versa [12]. However, more generally, service robots enable "contactless" approaches to techniques that would otherwise require an in-person human element. Researchers at Massachusetts Institute of Technology (MIT) repurposed the commercially available Spot™ from Boston Dynamics, a dog-like robot [13]. This robot was modified to include additional cameras, allowing contactless measurement of key vitals such as temperature, blood oxygen saturation and respiratory rate without human intervention. These tele-monitoring style systems may allow for workplace efficiencies as well, reducing undue burden on healthcare staff from frequent monitoring. A relatively easy extension to tele-monitoring is telepresence. Ava Robotics, a spin-off company of consume robotics company iRobot, offers telepresence robotic systems capable of spatially mapping and navigating environment [14]. This type of technology then enables a remotely placed clinician located in a risk-free environment to interact and engage with patients at the comfort of their own beds. This form of telepresence is useful to provide healthcare access from scarce experts, improving upon health inequities.

Service robots are no stranger in surgery. Surgical assistive systems have been present in various applications for several decades now [15]. While surgical care itself spans pre-operative assessments, imaging and planning up to, and including, post-operative recovery, the most abundant example of surgical robotics is in the operating room itself. Medtronic, one of the largest medical technology companies in the world, has offerings of spine and orthopedic systems (MAZOR™) that fully integrate with pre-operative imaging, and allow surgeons to achieve highly precise movements within an accuracy of a few millimeters [16, 17]. Knee and hip replacements have seen significant benefit from robotic systems provided by Mako Surgical [18, 19]. One of the most common surgical robot systems is the da Vinci surgical system™ from Intuitive Surgical (Sunnyvale, USA) [1, 20]. This tele-operated system facilitates surgeons improved workflow and ergonomics, extended degrees of motion, tremor filtering, and enhanced visualizations [1, 20]. In this setup, the surgeon is not directly operating the surgical instruments, but instead is manipulating them in a one-way feedback manner. In more recent offerings of the da Vinci™, integrated table motion allows for additional ambient capabilities to manipulate the surgical environment to the benefit of the surgery at hand [21, 22]. This feature allows the surgeon to leverage gravity assistance to manipulate patient position and internal organs by motion of the operating table, and the simultaneous movement of the robotic arms [21, 22]. The growth of commercially available products in surgical environments has simultaneously spurred an active area of research. Investigators now seek to add additional capabilities to these platforms. Examples of these pre-clinical abilities include task automation ranging from suturing, knot tying, and needle insertion in minimally invasive surgery, autonomous intra-operative ultrasound scanning, and automated camera control and motion as well as telerobotic capabilities [23–28]. However, while the first completely remote surgery was performed in the early 2000s, the ability to use this technology has remained elusive due to challenges in network bandwidth, latency, video communication.

Closely related are service robots in anesthesia which may provide oversight of patient management and procedures. This may include automated drug delivery of adequate anesthetic and analgesic medication through closed-loop control systems for monitoring and administration as well as management of medical devices such as adaptive ventilatory and circulatory support [29–31]. In the pharmaceutical delivery application, robotic systems which receive information directly from the patient by way of a suite of sensors could process such multi-dimensional high-resolution data in a manner human practitioners may be incapable of doing. In turn, there may be benefits to be seen through service robotics which respond in real-time to the patient needs with minimal guesswork required. In terms of circulatory support, the LUCAS robot system acts as an entirely mechanical and automated cardiopulmonary resuscitation device and has been shown to improve outcomes while obviating the need for manual chest compressions from support staff [32]. Beyond these applications, the use of robots to perform needle interventions for regional anesthesia and automatic intubation have been explored [33–35]. However, these systems remain largely pre-clinical in validation, with robust clinical benefit not yet shown.

3. Service robots in ambulatory care settings

While several of the applications (like sanitization, autonomous imaging, or robotic procedures) in acute care may extend into the ambulatory care setting, there are unique applications to consider. When applied to the ambulatory care setting, we consider service robots for the protection as well as empowerment and scaling up of the healthcare workforce.

In a similar fashion to environmental protection, service robots can protect the workforce from self-inflicted pitfalls such as fatigue risk. Chronic shortages of physicians and allied healthcare professionals leads to an overworked workforce, exacerbated by external stressors and cognitive overload, and resulting in a negative impact on attention, reaction, memory, and reasoning [36]. This in turn ultimately leads to inadvertent medical errors made by these well-intentioned individuals. It can also lead to increased psychological distress, insomnia, and depression [37–39]. Service robots in this roll could offload menial tasks and cognitive overhead so that healthcare workers could concentrate on more critical tasks related to direct patient care. In similar fashion, service robots could play the role of validation units in ensuring that health care workers are delivering the intended therapeutic to the patient in the right amount, at the right time, and in the right place. The notion of a robotic assistant has been well received by certain disciplines, such as nursing [40].

Leveraging of the workforce is another potential use of service robots in healthcare. Instead of one-to-one management between health care practitioner and patients, service robots allow for one healthcare practitioner to oversee the care (or subset thereof) for multiple patients simultaneously. This would have implications for health care delivery on a global scale such that fewer workers could provide access to higher quality care to a broader population of patients.

4. Service robots in At-home care settings

In the final section of this chapter, we examine the role of service robots in at-home care settings. In these settings, the patient is often not traveling to another institution to receive care. Instead, they either receive care from external providers in the comfort of their own home or are able self-administer care. In these diverse at-home settings, service robots may play a role in both delivering and providing actual medical care to patients but also in providing companionship and reassurance to those in times of need.

The evident application of robots at home is the use of telepresence. To address geographic disparities in equitable health access, as well as to reduce patient burden such as time and travel expenses, the use of telepresence enables clinicians to serve populations otherwise inaccessible [41]. In the simplest form, telepresence uses video communication apps available on smart devices or computers. However, more advanced immersive versions provide a physical mobile platform, allowing the user to move around the environment. Researchers have sought to automate classical physical examination techniques such as palpation [42] as well as advanced techniques such as ultrasound [42, 43]. While these technologies have not seen widespread integration in telepresence, one recent example is remote medical imaging. Imaging in remote areas is an exciting opportunity, as many communities lack individuals with the expertise to acquire and interpret high-quality images, providing a barrier to care. Clinicians in Saskatchewan, Canada deployed the MELODY system from AdEchoTech in a small study, finding that 92% of organs displayed on conventional examination were seen on those performed remotely, demonstrating the clinical feasibility of such remote imaging [44].

For individuals in rural and remote areas, or in emergent need such as in disaster relief, service robots can facilitate the delivery of medications and supplies. For example, drones themselves can travel fast and without geographical challenges. By leveraging these unnamed transport systems, drones could be used to distribute key medical resources to those in need. This is particularly advantageous in disaster settings whereby conventional transportation is not feasible [45, 46]. In commercial efforts of drone delivery, Zipline (San Francisco, USA) piloted blood distribution via drone delivery in Rwanda [47]. The use of service robotics for aerial transportation of medical resources resulted in a reduced transportation time of 4 hours to approximately 30 minutes [47]. Through coordinated efforts via fleets, drone delivery could extend to become an entire distribution network across entire communities.

Beyond the delivery of care, there is also the role of service robotics for self-care at-home. As exemplified by the COVID-19 pandemic, mental health including anxiety, depression and loneliness have increased significantly in the forefront of the general public's mind. As outbreaks occurred, entire long term care facilities were placed on "lockdown", restricting the movement of its patients and their visitors, for prolonged periods of time. In essence, these actions negatively impacted individuals' need for social interaction, a key component of one's mental health. How then can robots address this need? Through the patient-centered design of social robots designed specifically to assist in the emotional and mental well-being of patients. BUDDY, a companion robot offered by the company of the same name, is one such example [48]. The small mobile esthetically pleasing robot can provide the social interaction needed for elderly patients isolated from others while aiding with activities of daily living and fall detection. Likewise, the use of the PARO robot was demonstrated to provide both social and physical interaction benefits, as well as a potential increase in activity levels, in a cohort of patients with dementia [49]. For children, these robot systems can assist in neurodevelopment and socialization skills. One example is Moxie™ from Embodied, developed in-part by child development experts, for customized learning and play [50].

5. The challenges of service robots in healthcare

While the growth of service robot applications in healthcare is rapid, there are significant barriers to widespread adoption that are worth noting. The first of these challenges is regulation. Unlike consumer technologies, healthcare is heavily regulated with a stringent review process. This inherently causes a longer development process dependent on the scope of functions expected of the robot. As expected, the regulatory approval duration increases with the complexity and risk of these robots. In a medical setting, such as surgery, there is minimal margin for error as the consequences are often grave. This regulation lends itself to the second issue of liability. If a service robot is deployed, who is to blame for when it fails to perform correctly? If used to disinfect a room, and subsequent someone is infected, who at fault? Liability from a legal perspective must be carefully considered, especially as systems become increasingly autonomous. Third is privacy and ethics. To excel at their function, these service robots often require knowledge, or the ability to gather it, about their patient and need to be able to process that knowledge. However, this may require processing of the patient's personally identifying information including voice and face or require transmission of data outside of the robot. The risk of an unwanted intruder accessing such information is non-trivial. How privacy concerns for patients, providers, and insurers are all addressed in robotic settings is an ongoing area of investigation.

The practical deployment of these robots also remains a barrier. While there is promise, significant portions of the core technology – particularly those that require interaction with healthcare workers or patients – remains experimental in nature. It remains to be seen, even with existing widely used medical service robots, whether the benefits promised by these systems is realized. These systems may vary in performance depending on environmental conditions such as network capabilities, audio noise, lighting conditions, battery life, and so on. This leads to the final remaining barrier to deployment: cost. The expense of manufacturing and equipping these robot systems often requires a large initial capital investment, as well as a barrage of consumables and maintenance requirements. It further requires additional training for staff, re-vamped workflows, and commonly institutional willpower to continue to support the systems. These fixed and variable expenses need to be sufficiently mitigated by the potential or realized gains of robotic system use.

6. Conclusion

In summary, service robots in healthcare are seen as potentially playing many roles within the patient care setting. In many ways, the health care industry could benefit from increased automation which has been notably absent from this ever-important area. Patients, health care workers, institutions, insurance companies and governments will find that service robots bring significant benefits in terms of leverage and cost reductions in the future while maintaining or improving access, equity, and high-quality health care.

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Conflict of interest

The authors declare no conflict of interest.

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