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Classification of Healthcare Robots

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Abstract. With the advancement of artificial intelligence, robots have entered the healthcare field and provided various intelligent services. Compared to the growing number of use cases for healthcare robots, conceptual, and theoretical research on healthcare robots is still in its infancy. There is a need to explore how healthcare robots play different roles in society with the improvement of AI technology. To fill in this research gap, we provide a conceptualization of healthcare robots and a summary of main categories of healthcare robots in previous research. This study provides a classification of healthcare robots according to their service roles and discusses their differences in different dimensions, including appearance, presence, AI and automation ability, and social ability. Finally, we propose future research directions based on the discussion to provide insights into the conceptualization of healthcare robots. This study contributes to IS literature by providing a comprehensive knowledge base for further theory-building processes of AI-based healthcare robots and providing design guidance to robotic designers in specific healthcare fields.

Keywords: Healthcare robots, Artificial intelligence, Classification, Service roles.

1 Introduction

The potential impact of robotics combined with artificial intelligence and machine learning on front-line workers in various industries is of great concern to business practitioners. Robots are often thought to perform human-like tasks, and they rely on the success of information technology in artificial intelligence to accomplish these pursuits [1]. In healthcare, robots are helping patients, healthcare professionals, and healthcare systems in various ways to improve people's health and well-being [2, 3]. In the early days, robotic systems in healthcare were commonly used for surgical assistance, diagnosis, prosthetics, and nursing assistance [4]. Advances in the field of artificial intelligence have transformed robotics from passive entities to active entities and agents. Especially since the outbreak of COVID-19, the service role of health robots is rapidly being re-evaluated, starting to be used in more expansive fields such as disinfection, telemedicine, psychotherapy, and companionship [5]. It can be seen that the co-evolution of artificial intelligence will make healthcare robots more integrated into the real world and provide complex services to people. However, there are still many obstacles to be overcome before they can successfully integrate into society.

Studies on healthcare robots have been continuously increasing in the past couple of years. Some studies have investigated how healthcare robots can enhance the health and well-being of consumers [6, 7], their effectiveness [8, 9], and users' perception regarding different healthcare robots [10, 11]. Compared to the growing number of use cases for healthcare robots, conceptual and theoretical research on healthcare robots is still in its infancy. With the continuous development of artificial intelligence technology, how healthcare robots play different roles in society with the improvement of artificial intelligence capabilities has not been fully explored.

To fill in this research gap, we provide a conceptualization of healthcare robots and their main categories with the development of artificial intelligence. Specifically, we classify healthcare robots into three categories based on their service roles in healthcare contexts: healthcare robots as functional tools, healthcare robots as service assistants, and healthcare robots as social colleagues. Then we discussed the differences between the three kinds of healthcare robots from the dimensions of appearance, presence, AI and automation ability, and social ability. This study hopes to provide some insights into the theoretical research of healthcare robots in the context of artificial intelligence and help healthcare managers, designers and employees better understand the design features and service roles of different healthcare robots to adopt and utilize specific healthcare robots.

This paper is organized as follows. The definitions and classifications of healthcare robots in the literature are presented in the background section. Then a classification of healthcare robots is proposed based on social roles in section 3. Finally, the contribution and limitations of this study are highlighted.

2 Background

2.1 Definitions of healthcare robots in literature

The term "robot" has been widely discussed in the research. From a technical perspective, robots are defined as machines capable of performing a complex series of actions, they can make autonomous decisions and adapt to their environment

based on data received from various sensors and other sources. With the advancement of artificial intelligence, the development of robots is further encouraged. The Ministry for Health, Labour, and Welfare (MHLW) defines a robot as an intelligent mechanical system with three technical elements of perception, judgment and operation. Perception represents the sensor system, judgment represents the control system, and operation represents the driving system [12]. From a service perspective, a robot is defined in the service industry context as a relatively autonomous physical device capable of moving and performing services. As robots' service roles continue to extend, robots are considered human agents acting in real-world environments [13]. Software agents may be included in some definitions [14].

When robotics enters the healthcare field, various applications and research continue to emerge. Academics are beginning to define healthcare robots in their research. Table 1 summarizes the definitions of healthcare robots in the literature. Some common synonyms for healthcare robots are carebots and nursing robots. It can be seen that the current research mainly discusses the definition of a healthcare robot from two perspectives: function and role. From the functional perspective, a healthcare robot is defined as a robot that can enhance and detect health and assist various tasks related to health [4]. From the perspective of the role, health robots are considered nursing devices that can be used to support users' self-reliance or reduce the burden on caregivers [15].

Considering the complex functions of healthcare robots and various application contexts, we believe that a more flexible definition of healthcare robots is given. In this paper, we define healthcare robots as autonomous or semi-autonomous machines with a certain degree of intelligence that performs various complex tasks in various healthcare contexts.

Table 1. Definitions of healthcare robots in literature.

Definition	Source
A healthcare robot is a robot with the aim of promoting or monitoring health, assisting with tasks that are difficult to perform due to health problems, or preventing further health decline. Health in this sense encompasses not just physical but mental, emotional, and psychosocial problems.	[12]
Robots have been proposed as one form of assistive device that can help bridge the widening gap between the need and supply of healthcare services.	[13]
Carebots are robots designed for use in homes, hospitals, or other settings to assist, support, or provide care for the sick, disabled, young, elderly, or otherwise vulnerable persons.	[14]
Systems are able to perform coordinated mechatronic actions (force or movement exertions) based on processing information acquired through sensor technology to support the functioning of impaired individuals, medical interventions, care, and rehabilitation of patients, and also individuals in prevention programs.	[15]
Robots used within the field of healthcare encompass varying degrees of autonomy and broadly include affiliated technology, including sensor systems, algorithms for processing data, and cloud services.	[16]
A nursing robot is defined as nursing equipment that has these elements and can be used to support the user to be self-reliant or to reduce the burden of the carer.	[17]

2.2 Classifications of healthcare robots in literature

Some taxonomies have been proposed in research to differentiate and classify healthcare robots. Table 2 summarizes some commonly used classifications of healthcare robots in literature. Healthcare robots can be classified according to various dimensions, such as function, task, context, and target users. Given all this evidence, there seems to be no gold standard or taxonomy for which technologies and robotics applications can be included in a particular field of healthcare robotics. Moreover, with the combination of artificial intelligence and robots in healthcare, the service functions, roles, and scenarios of robots in healthcare continue to expand. It is necessary to continuously update and create the classification of healthcare robots based on service perspectives.

Table 2. Classifications of healthcare robots in literature.

Dimension	Category	Source
Function	(a) rehabilitation robots; (b) social robots (service type robots or companionship robots)	[12]

	(a) therapy robots; (b) mental commitment robots; (c) socially assistive robots; (d) surgical assistance robots; (e) robot-assisted telesurgery; (f) rehabilitation robot; (g) robots to aid elderly	[18]
	(a) surgical robots; (b) assistive robots (socially assistive robots or physically assistive robots); (c) healthcare service robots	[19]
Tasks	(a) surgical robots; (b) robots that aid with rehabilitation therapy, help the disabled and cognitively impaired maintain their independence, and motivate people to exercise and lose weight; (c) robots used for telemedicine; (d) robots that deliver meals, medication and laundry in hospitals.	[13]
	(a) rehabilitation/prosthetic robots; (b) patient support robots; (c) surgical robots; (d) imaging and navigation robots; (e) decision making robots; (f) bionic robots; (g) automated pharmacy robots	[20]
Target users	(a) doctor healthcare robots; (b) nurse healthcare robots; (c) home healthcare robots	[21]
Medical context	(a) clinical robots; (b) nonclinical robots	[22]

3 The proposed classification of healthcare robots

Drawing on the recent literature on healthcare robots and the need for robotic service roles in the current healthcare environment, we can develop a classification in which healthcare robots can be differentiated according to different types of service roles. In this paper, we conceptualize healthcare robots as three distinct types: healthcare robots as functional tools, healthcare robots as service assistants, and healthcare robots as social colleagues. This classification attempt to capture the design, technology, and application characteristics of different types of healthcare robots from multiple dimensions, such as appearance, presence, AI and automation capabilities, and social capabilities. Table 3 summarizes the main characteristics of the three kinds of healthcare robots.

Table 3. The proposed classification of healthcare robots

Type	Healthcare robots as functional tools	Healthcare robots as service assistants	Healthcare robots as social colleagues
Appearance	Mechanical	Mechanical / Humanoid / Animal-like	Humanoid / Animalization/virtual
Presence	Copresence / Telepresence	Copresence	Copresence / Virtual agents
AI and autonomy capability	Non-AI autonomy	AI semi-autonomy	AI pseudo-autonomy
Social capability	Non	Low/mediate	High
Examples	The neuroArm robotic system, the Rex (Robot Exoskeleton)	Healthbot, Charlie	Paro, Pepper, Alice

3.1 Healthcare robots as functional tools

Healthcare robots as functional tools are the first and most widely used healthcare robots. Robots in this category refer to robots consisting of mechanical aspects used to accomplish some given medical task [23]. At work, they can be in the same physical space as the user, also considered copresence. At the same time, those proxies that appear on a screen or projection as a live video feed are also considered “telepresence” [24]. In terms of AI capabilities, healthcare robots as functional tools are usually non-AI autonomous robots that are programmed to perform repetitive actions to achieve the user's goals until they are deactivated [25]. The decisions they make do not contain uncertainty because they are used in a known environment. These robots usually can control their execution entirely autonomously, and the tasks they perform

are not complex, so they do not have the ability to learn, reason, and interact [26]. That is to say, this type of robot cannot participate in and maintain various complex social interactions.

Examples include surgical robots, cleaning robots, robotic skeletons, and medication dispensing robots. For example, the neuroArm robotic system has been successfully used in hospitals. It is used in conjunction with real-time magnetic resonance imaging (MRI) to provide surgeons with unprecedented detail and control, allowing them to manipulate tools at the microscopic scale [27]. The robotic system includes two robotic arms, each with six degrees of freedom, and the third arm with two cameras that provide a 3D stereoscopic view. Introduced in 2010 by Rex Bionics, New Zealand, the Rex (Robot Exoskeleton) is a pair of robotic legs that allow users to stand and walk freely, move sideways, turn around, and move their feet up and down, designed to overcome wheelchair movement by restoring the user's ability to walk limit [28]. As robotics becomes more sophisticated and responsive, the use of such robots in the healthcare field continues to increase.

3.2 Healthcare robots as service assistants

This category of healthcare robots refers to robots that act as human assistants to assist in performing various tasks and provide health services in a healthcare environment [13, 29]. AI semi-autonomous healthcare robots can react to their environment and operate without constant supervision to perform more complex tasks [30]. They can change execution according to the context within the set predefined limits to a certain extent. Artificial intelligence provides a mechanism for integrating human-like reasoning and computing power into control systems. They can adjust goal setting within a range, and the types of decisions they make contain low levels of uncertainty because they are context-aware and learn to improve to a certain extent from their experience and user feedback [31]. They can identify, process relevant information about the situation, and make sensible decisions about what to do.

Research has shown an intricate relationship between the anthropomorphic image of a machine and the perceived service value. Healthcare robots of this type are primarily co-occurring while developing from a mechanical appearance to a human-like appearance. For example, some assistive service robots are helping healthcare staff focus on other essential aspects of the hospital by helping patients walk or monitoring their health [32]. Before artificial intelligence and robotics advent, tasks such as helping patients walk, assisting with patient examinations, and taking patient medical histories were manual and time-consuming [33]. Today, however, these tasks can be easily automated and performed quickly by machines. In such situations, staff is often eager to assist the patient rather than perform other tasks. As a result, those assistive robots can aid with activities of daily living (such as heavy lifting and logistics, monitoring, mobility, and safety detection) and basic nursing tasks (such as vital signs measuring and fall detection). At the same time, humans spend more time with patients [34]. With the advancement of technologies such as machine learning, data analysis, and artificial intelligence, healthcare robots will develop as assistants in the service field to complete tasks more autonomously, efficiently, and accurately.

3.3 Healthcare robots as social colleagues

In addition to functional tools and service assistants, there are also healthcare robots as social colleagues. This type of healthcare robot is designed to attempt to act as a healthcare professional colleague, providing services to end-users in the roles of doctor, therapist, navigator, personal caregiver, and friend [35, 36]. They serve users in a healthcare setting by engaging and maintaining social interactions with humans. They can interact with humans and the physical environment in a virtual or copresence manner [34]. A high degree of humanization and animalization is a trend, and some virtual agents are also included. Such AI pseudo-autonomy robots can self-organize, that is, construct their means and laws of operation to achieve satisfactory performance without experience and compensate for system failures without external control [34]. They assume interactive elements in non-deterministic systems and are able to interact with other objects, process information, evaluate alternatives, and thus make decisions on their own [37].

This type of healthcare robot is mainly in the research and development stage. These AI-based intelligent robots can perform operations and augment the work of physicians with specific diagnostics and treatment methods, reduce cost and time, and improve response time to patient needs when healthcare personnel are unavailable [38]. For example, the humanoid robot Zora has been used in public elderly care services in Lahti, Finland, for rehabilitation and recreational assistance with exercise, playing music, performing dances, story-telling, and playing interactive memory and guessing games [39]. Patients suffering from depression and other mental illnesses have gained comfort, pleasure, calmness, and approachability in the robotic experience [40]. In dementia treatment, an animal-like robot called Paro could alleviate the behavioral and psychological symptoms of dementia like anxiety, agitation, and depression and provide distraction and interrupt problematic behaviors [41]. Therefore, healthcare services are no longer an isolated silo of healthcare personnel.

The advancement of artificial intelligence will significantly expand the application of robots in different healthcare contexts. This trend is expected to accelerate in the future.

4 Conclusion

With the advancement of artificial intelligence, a large number of healthcare robots have been invented and entered the market. However, only a few of these devices are widely accepted to coexist in the human environment. In this paper, we classify healthcare robots according to their service roles and clarify the differences in design characteristics between the different categories identified, adding to the existing knowledge and conceptual understanding of different types of healthcare robots. This classification can provide a comprehensive knowledge base for further theory-building processes of AI-based healthcare robots and provide design guidance to robotic designers in specific healthcare fields. At the same time, in terms of practical contribution, this classification may help practitioners understand the status quo of the development of healthcare robots and promote the development of healthcare robots in specific fields. In our future research, we hope to build a clearer and more consistent conceptual framework considering the robot's design features, functions, technology, service scenarios, and other aspects.

This paper discusses the limited characteristics of healthcare robots that may limit our comprehensive understanding of healthcare robots. It is necessary to consider different dimensions such as the design features, functions, technologies, and service scenarios of robots to build a clearer and more consistent conceptual framework. At the same time, advances in AI technology are breaking down the boundaries of healthcare, well-being, and life itself [37]. In the future, a comprehensive conceptual understanding of intelligent health robots should be constructed from a more comprehensive and dynamic perspective.

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