Medical Robots

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The combination of artificial intelligence technology and medical science has inspired the emergence of medical robots with novel functions that use new materials and have a neoteric appearance.

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1. Introduction

Over the years, robotics and artificial intelligence (AI) have been introduced into the daily lives of most of the world's human population. Among the breakthrough technologies that have enabled the development of new medical devices, medical robotics is one of the most successful examples [1]. Medical robots have been utilized in multiple areas to assist humans with tasks that are repetitive, carry significant risk or require specific precision or some form of sophisticated complex ability. Novel usages for medical robots are found and described regularly [2]. During the evolution of medical care, the great advantages of medical robots have been confirmed in clinical diagnosis [3], surgical treatment [4], postoperative rehabilitation [5], home care [6], and other fields. Medical robots will certainly become increasingly important over the next few years [7][8]. In a way, medical robots have been integrated into every aspect of human life, and research and innovation of medical robots continues to develop various medical robots with different design purposes, applications, structures, materials, and intelligence levels.

1.1. Exploration in Medical Institutions

Robotic devices with medical auxiliary functions are now widely used in most medical institutions. Surgical robots, having been applied in medical institutions, have brought great breakthroughs for the medical industry. The first published robot in human surgery was in 1985 for a brain biopsy using a computed tomography (CT) image and stereotactic frame [9][10]. A few decades later, ROBODOC [11][12], which was developed by Computer Motion (Santa Barbara, CA, USA), was integrated with computer-aided technology by the Integrated Surgical Systems (ISS) company (Champaign, IL, USA) AESOP [13] for use in orthopedics; the ZEUS robotic system [14][15][16][17][18] was developed by Computer Motion and applied in internal medicine; and Da Vinci robot systems Standard (1999), S (2006), Si (2009), and Si-e (2010) [19][20] were developed by Intuitive Surgical for other medical departments.

Besides benefiting from the technological innovation, so-called "service robots" are used to serve medical staff and patients and have developed significantly. Service robots in hospitals are highlighted because of their potential scientific, economic, and social expectations. Service robots help nurses to guide, transport, clean, inspect, monitor, and disinfect, providing an important service for patients. At present, obstacle avoidance strategies [21],

interactive control strategies (voice or gesture) [22], and humanoid structure design [23] have become hotspots of development to better meet the needs of clinical and hospital services. With the help of technological innovation and research enthusiasm support, the development prospects for service robots are good.

1.2. Progress in Home Care

The rapidly growing population of elderly people and improvements in the quality of life have resulted in an increased need for home care robots in daily life. Up to now, the different types of home care robots have mainly provided assistance with daily tasks, monitoring behaviors and health, and providing companionship [24][25][26]. As prominent examples, Care-O-bot [27], Robot-Era Robots [28], Zora [29], Justo Cat [30], and PARO [31] have received excellent evaluations. A previous study reported that these robotic technologies make it easier to live alone and provide a relatively better quality of life for a longer time [32].

1.3. Novel Materials and Appearances

Ranging from professional service robots used for surgical, rehabilitation, or nursing purposes to personal robots for diagnostic, medical teaching, or entertaining use, medical robots are becoming ubiquitous. Nowadays, accounting for the cultural diversity in the personal background of people is of high importance for the designers of robotic devices [33]. Therefore, medical robots with different appearances, materials, and structures have been developed to perform different tasks to meet medical requirements and user preferences.

In minimally invasive surgery (MIS) applications, the soft medical robots that can navigate narrow gaps and move, deform, and interact with soft organs have high demand. Controllable stiffness, utilized in laparoscopic surgery and endoscopy, and a tactile sensor sleeve for soft manipulators have been developed to overcome limitations in lack of haptic feedback [34][35].

In home care, humanoid robots are more popular, while in clinical applications, structural stability is one of the necessary conditions for medical robots. The printed humanoid robot [36] can perform dancing and show human-like facial expressions to provide entertainment and assistance to children and elderly people. The Humanoid Robot NAO [37] can be used as a trainer in a memory program for elderly people with mild cognitive impairment. At present, in addition to the requirements of precision and function, researchers are gradually paying more attention to the appearance and materials used in the construction of medical robots.

1.4. Difficulties in Diversified Development of Medical Robots

The rapid progress in medicine is driven by a combination of technological improvements (motors, materials, and control theory), advances in medical imaging (higher resolutions, magnetic resonance imaging, and 3D ultrasound), and an increasing acceptance of robotic assistance. Nowadays, medical robotics are ubiquitous and relied upon in most professional and living environments. Medical robots with different types, functions, and shapes have been gradually manufactured as a result of vigorous research and development.

The characteristics and technical preferences of medical robots used in disparate fields to meet various demands differ widely. In general, more attention will be paid to the precision requirements of medical robots used in medical institutions, while it will lay more emphasis on the interactive capabilities and intelligence of medical robots used in home care. The proliferation of different types of medical robot makes it difficult to generalize technologies in a single field. If the medical robots applied in the same application field and equipped with identical technical requirements can be effectively classified, it will be conducive to discussion and technical innovation. Besides, due to the wide variety of medical robots, it is difficult for people, especially the general public, to effectively distinguish the categories of medical robots. The classification of medical robots can help people in various industries distinguish types of medical robot, and understand the characteristics and other information of the corresponding types of medical robots.

Researchers have proposed several classification methods according to personalized needs. To date, classification schemes have been proposed that take into account the usage scenario, appearance, control manner, and construction material used. However, it is difficult to find a method to meet the requirements for the general public and studies, which does not result in lower recognition and a failure of communication among experts and professionals. In practical terms, it also means that most of the existing classification methods are not conducive to technical exchanges in related fields and may affect the technical development of medical robots.

There is no doubt that a reasonable classification strategy for medical robots would not only help to identify the type of robot more effectively, but would add impetus to the development of robotics technology. The reason why we performed this research lies in the fact that, despite the growing popularity of medical robots, there are some defects in their classification. Given the creative and novel medical robots likely to be developed in the future, it is important to improve the applicability of the classification method to existing and upcoming technologies. To solve these classification problems, the present classification methods and corresponding defects are reviewed, after which an innovative classification strategy for medical robots is proposed. In addition, we review the development status of several medical robots, through which we highlight the necessity of the secondary classification of surgical robots and rehabilitation robots. On this basis, we provide secondary classifications for surgical robots and rehabilitation robots, by which distinctive features can be shown and the communication between researchers in that or other fields can be improved. The article is concluded by providing an outlook of recommendations for medical robots in the future.

2. Definition and Characteristics of the Main Types of Medical Robot

2.1. Surgical Robots

Surgical robots refer to medical robots that are routinely used in surgery and used as medical equipment in integrated disciplines such as medicine, mechanics, biomechanics, and computer science. The existing surgical robots offer increased dexterity to surgeons [38][39].

With the evolution of medical techniques and instrumentation, AI technologies such as computer vision technology, speech recognition technology, long-distance communication technology, and three-dimensional imaging technology are gradually being incorporated into the surgical robot system. Surgical robots that have emerged over recent years have reached a high level of accuracy and feasibility in minimally invasive surgery but have aroused widespread concern in the academic community [40][41][42]. At present, the main characteristics of surgical robots are as follows:

(a) Minimal invasion: The less invasive the surgical intervention, the greater the role of AI and the performance of specific tasks by medical robots [43]. Compared with traditional open surgery, one of the most significant advantages of surgical robots is fewer traumas, which can greatly reduce surgical wounds, shorten the recovery period of patients, and reduce the pain of patients.

(b) High precision: Generally, surgical robots are provided to serve surgeons and patients. As one of the most prominent factors, the accuracy of surgical robots will directly affect the health and safety of humans. In the clinic, it is imperative that the safety and stability of the surgical robot can be guaranteed. Compared with traditional surgery, surgical robots have improved accuracy.

(c) Wide range of surgical applications: due to the continuous optimization of driving and controlling manner, surgical robots are being selected by more and more departments in the hospital to perform surgical operations, resulting in an extensive increase of their application fields.

(d) High sensitivity: As an important index affecting the working range, the sensitivity of medical robots is selected to characterize the working ability. By integrating sensors at proper positions, the sensitivity of surgical robots would be improved.

2.2. Rehabilitation Robots

Rehabilitation robots refer to the devices that can automatically perform tasks to replace or assist certain functions of the human body, thereby playing a role in the rehabilitation process [44]. Rehabilitation robots currently play an important role in the functional reorganization and restoration, as well as metabolic compensation, of the nervous system, and the remission of muscle atrophy and joint atrophy. With the rapid expansion of intelligent control technology, network technology, simulation technology, and new material technology, the research and application of rehabilitation robots has increased the speed of the evolution process and accelerated the progress of related fields [45].

Rehabilitation robots need to be modified and optimized constantly to better meet the needs of patients. Compared with traditional methods, rehabilitation robots can drive patients for rehabilitation training with several advantages as follows:

(a) Single operation and strong repeatability: Rehabilitation robots (e.g., intelligent wheelchair, exoskeleton device, and training device) are often used to provide auxiliary services for disabled people. It is necessary for these

processes to consume a large amount of time to execute simple and repetitive tasks and perform the set functions. Rehabilitation robots provide perfect training and service functions for strength, accuracy, and consistency in sports.

(b) Personalized training: taking into consideration the severity of the injury and duration required for the recovery process, personalized training can be performed, and individual features, modes, and structures of rehabilitation robots are required.

(c) High integration: A variety of sensors are usually integrated into rehabilitation robots with powerful information processing capabilities. By integrating sensors, kinematic and physiological data from patients can be recorded and measured during the process of rehabilitation training, and these data can be fed back to the robots in real-time so that the rehabilitation and training progress of patients can be quantitatively evaluated to provide the basis for surgeons to improve the treatment plan.

2.3. Medical Assistant Robots

Medical assistant robots are defined as robotic equipment, with patients as their service objects. They are used to substitute or support the hospital staff to perform medical transactions including examination, diagnosis, guidance, and disease analysis. The most prominent feature of medical assistant robots is that they replace nurses and physicians to provide diagnostic and treatment-related services to patients. Throughout the detection of disease and treatment, almost all operations related to medical procedures can be performed by medical assisted robots. Their use is not limited to hospitals, as they also have applications in daily life. At present, automatic medical diagnosis, monitor, health examinations, and other medical auxiliary work can be performed at home.

Medical assistant robots have been used to assist medical staff, and in aspects of diagnosis and examination, automatic diagnosis robots are popular. As a symbol of technological progress, capsule robots have revolutionized diagnostic procedures in the gastrointestinal tract by minimizing discomfort and trauma. A capsule endoscope robot called NaviCam™ [46] has been used in many medical examination centers. Previous research [47] proposed a magnetically actuated soft robotic capsule robot to improve their diagnostic accuracy for submucosal tumors or diseases. Another study [48] designed a novel capsule robot with the ability to move forward and backward, as well as turn, achieving the rendezvous and separation action through the three-dimensional rotating magnetic field.

During the outbreak of COVID-19, some hospitals recognized the significance of robots. Medical assistant robots were used to provide hospital guidance, intelligent triage, automatic diagnosis, business consultation, and other services.

With an increasing range of applications, the main characteristics of medical assistant robots used at medical institutions are reflected as follows:

(a) Professionalization: To perform specific medical operations, such as disease diagnosis, prediction, parametric analysis, and inspection, medical assistant robots are equipped with expertise and endowed with high accuracy to

perform specific procedures. This means medical assistance robots can be designed to perform purpose-specific tasks to achieve assistance in various medical environments.

(b) Timeliness: During interactions with patients and doctors, it is necessary to quickly and accurately feedback the information required to improve the application experience. In the process of diagnosis and testing, a timely response can help patients and doctors get results as soon as possible, which reduces time costs, and means relevant treatment can be performed when necessary to avoid delays during illness.

(c) A rich library of experts: With their high degree of AI technology, medical assistant robots can detect health parameters, diagnose diseases, and provide rationalized suggestions by detecting the biological characteristics of patients. These all require the support of a strong expert database to provide intelligent diagnosis and treatment programs. During the application process, the professional knowledge and experience of the robot are also constantly being optimized and enriched.

2.4. Hospital Service Robots

Hospital service robots are robotic devices used in hospitals or other medical institutions to provide services unrelated to medical operations. Controlled by a particular person in medical institutions, hospital service robots are used to carry out ancillary tasks unrelated to medical operations such as transportation, disinfection, transfer, and cleaning. The usage of hospital service robots greatly enhances the service quality for patients and reduces costs for medical institutions.

The usage of hospital service robots can effectively relieve staff pressure and provide constant service on all days [49]. Besides, hospital service robots also help patients to take medicines by delivering medicines and supplies only at the assigned location. The HelpMate [50][51], which was developed by the American Transportation Association, can transport food and medicine in hospitals. The TimRob [52], developed by Shanghai TimRob Technology Co. Ltd. (Shanghai, China), provides services in nuclear medicine wards such as propaganda and education, physical examination, radiation measurement, item distribution, remote video, and environmental monitoring, etc.

Hospital service robots provide great assistance for medical staff and patients alike, and they generally have the following characteristics:

(a) Anthropomorphic appearance: to improve interactions with humans, hospital service robots are mostly designed as anthropomorphic structures, on the assumption that an attractive appearance will be favored by the public.

(b) Convenient movement: These robots must be developed to move in most scenarios while cleaning, disinfecting, transporting and transmitting. Flexible mobility is, therefore, a common characteristic of hospital service robots. Moreover, the easy-to-move feature can reduce the limitations of robot application scenarios.

(c) Easy to operate: The simple and convenient operation method reduces the learning time and adaptation time of the operator, and it makes it easier to be promoted and applied.

Both medical assistant robots and hospital service robots provide convenience to patients and medical staff. The significant difference between them lies in the usage purpose and the person who operates the robots. Medical assistant robots are used to provide auxiliary tools for medical processes, and the operators are professionals, such as surgeons and nurses in hospitals, or patients themselves. However, hospital service robots perform work unrelated to the medical process, and the operator is the specific staff member.

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