Research Progress and Prospect of Nursing Robot

Jingang Jiang1,*, Zhiyuan Huang1, Biao Huo1, Yongde Zhang1 and Shichang Song2

1Robotics & ITS Engineering Research Center, Harbin University of Science and Technology, Harbin 150080, P.R. China; 2School of Foreign Languages, Harbin University of Science and Technology, Harbin 150080, P.R. China

**Abstract:** Background: With the elderly population increasing at a phenomenal rate in the world, the disabled elderly care has become a hot issue concerned with society and government. The latest survey showed that the elder, who wish to grow old in their own house, is more than 85%. It is a pending problem that how to meet the elder’s need and relieve the burden of society and their children. The nursing service market could reach 3.3 trillion yuan in 2020, and then the technology industry of elderly nursing will grow into a new increasing point for the national economy. Therefore, the informatization and robotization of elderly nursing will become the necessary development trend in the future.

**Objective:** To provide an overview of the existing nursing robots and introduce their classification, characteristics and development.

**Methods:** This paper reviews various productions and patents related to the nursing robot. The structural characteristics, differentiations and applications of the typical nursing robot are also introduced.

**Results:** The three types of the nursing robot are compared and analyzed, and the typical characteristics are concluded. The main problems in its development are analyzed, the development trend is foreseen, and the current and future research of the productions and patents on the nursing robot are discussed.

**Conclusion:** Nursing robots are divided into an independent nursing robot, rehabilitation nursing robot bed and multifunctional mobile nursing robot. The nursing robot has important practical significance for promoting social nursing services, and it plays an important role in improving nursing quality of patients and the elderly and reducing the pressure of nursing staff. Further improvements are needed in the aspects of reliability, comfortable capability, humanization, intelligence and security of the nursing robot. More patents on nursing robot should be invented.

**Keywords:** Design requirements, independent nursing robot, multi-functional, nursing, nursing bed, rehabilitation.

1. INTRODUCTION

With the continuous improvement of living standards and medical standards, aging population has drawn great public attention. However, most of the elderly are lacking the ability to take care of themselves. According to a survey, less than 40% of the elderly aged over 80 have the ability to care for themselves [1]. More families are finding themselves unable to look after aged relatives who are unable to look after themselves. The elderly nursing has become a social issue.

With the rapid development of science and technology, the nursing robot has come into being. The nursing robot is designed specifically for the elderly and disabled people, who lack self-care ability. And this robot can help them to restore part of their self-care ability, and effectively reduce the social problems caused by aging [2]. As a medical robot, the nursing robot can help to move the patient, who is disabled or unable to move himself, onto the wheelchair. It possesses the good human-computer interaction ability. The patient can observe and record the living habits of the elderly patient, or remind patient to take medicine, and change dressings. The nursing robot can also perform typical rehabilitation actions, such as rehabilitation of hand functions [3], waist rehabilitation [4], ankle rehabilitation [5], lower limb [6] and upper limb rehabilitation [7, 8]. However, rehabilitation robots or rehabilitation equipment are relatively specialized to a specific patient, and these devices cannot be used universally. Furthermore, the rehabilitation will be limited by the mechanical structure. In contrast, nursing robots are versatile and have a wide range of applications applied to any population. In particular, humanoid nursing robots generally have a lovely appearance,
and its surface material is soft, so it can provide a comfortable interactive scene. The nursing robot can not only nurse the patient’s injuries, but also increase the psychological comfort of patients and nursing staff. As a result, nursing robots have had a rapid growth in recent years.

The reasons for the rapid development of nursing robots are further summarized. The four reasons are as follows:

1.1. Aggravation of Aging Society

The population aging has caused changes in social structure, family structure and pension structure. Till now, the population structure has evolved into an inverted pyramid structure. Most elderly people have a decline in their physical functions, and their vitality has already decreased. They will face many difficulties and obstacles, and their daily life is unattended. More and more elderly people need prompt nurse services to ensure their safety. This is a serious challenge to the cause of nursing.

1.2. Health Damage of the Elderly

Most of the elderly are of temporary disability and belong to sub-health groups. The elderly with functional disabilities face a variety of living difficulties.

1.3. Insufficient Social Nursing Service

Nursing services are facing serious challenges and directly stimulate the domestic nursing robot market, especially in countries with a great population. The society urgently needs intelligent nursing equipment and applies it to families and nursing homes.

1.4. National Laws and Regulations Support

National governments successively promulgated a series of laws and policies to protect the legitimate rights of the elderly and disabled. National protection and laws improved the life quality of the elderly and promoted the development of nursing.

It can be concluded from the above four points that the nursing robots are developed with the improvement of medical care level and robot technology, and it has brought new vitality to nurse the disable patients and elderly. The nursing robot can not only reduce the work intensity of the nursing staff and improve the nursing efficiency, but also enhance the self-nurse ability and adaptability of the patients and elderly. Therefore, nursing robots have become one of the research hot topics in recent years.

In today’s background, nursing robots conform to the needs of social development, providing a new direction for medical equipment, thus we should pay attention to the development of nursing robot, so that it can bring us more benefits.

2. DESIGN REQUIREMENTS AND CLASSIFICATION OF NURSING ROBOT

2.1. Design Requirements of Nursing Robot

In 1980, the American Nursing Institute proposed a formal definition of nursing which is the diagnosis and treatment of human response to the existing or potential health problems. Based on this definition, the nursing robot should be able to make an accurate diagnosis and effective treatment for people’s health problems. So, their main task is to make accurate judgments and treatments according to different groups of people, diseases, emergencies and other issues. Therefore, the design requirements of the nursing robot are as follows [9, 10].

2.1.1. Safety and Stability

Nursing robot mainly targets at special groups who are aged or have disease and other patients who have long time bedridden with the disease. These patients act and response slowly, and they cannot give prompt response to emergencies. Therefore, the safety and stability of nursing robot are particularly important to ensure the safety of patients, and this is the primary design principle. The design of the nursing robot should be in accordance with the structure, control and debugging to ensure its safety and stability.

2.1.2. Humanization

As a service-oriented robot, the nursing robot should follow the principles of humanization design. As an important design factor, the humanization design of nursing robots should consider the ergonomic principles to handle the man-machine relationship, the human behavior, and psychology. Following the human nature, this makes the nursing robot serve much better with the human.

2.1.3. Intelligence

In order to make the nursing robot complete the task, we should improve the intelligence of the nursing robot. Thus, the nursing robot should be able to record information and life style of human in daily life. Meanwhile, the human-machine interaction system of nursing robot should be established.

2.1.4. Standardization and Modularization

The design of nursing robot should follow the standardized and modular design ideas. It can improve stability and shorten the development cycle and design costs. At the same time, the design principles of standardization and modularization will also be conducive to the maintenance of nursing robot.

2.2. Classification of Nursing Robot

In recent years, various nursing robots have been designed. It can generally be classified as three categories: independent nursing robot, rehabilitation nursing robot bed and multi-functional mobile nursing robot.

Independent nursing robot helps the elderly and inconvenient patients to automatically clean the defecation. The robot’s sensor can detect the position of defecation and clean up the dirt. This independent nursing robot also has functions of cleaning and dehumidification, and some of the nursing robots also has the function of anion purification. It can eliminate mildew and odor [10].

Rehabilitation nursing robot bed is designed for patients who need long-term bed rest, using rehabilitation care equipment, which can turn the left side, turn the right side, turn around, defecate and so on [11]. Rehabilitation nursing robot...
bed is mainly used in hospitals and homes for medical care. It is mainly nursing for the elderly and disabled. Given the long-term bedridden, their limbs cannot be stretched. The nursing robot bed provides the function of upper and lower limb rehabilitation exercise and muscle massage. Rehabilitation nursing robot bed not only gets rehabilitation of bones but also promotes limb blood circulation. It also can provide the patient with vital signs of the test and configure cameras for assisting the paramedic to monitor the situation of patient [12].

The multi-functional mobile nursing robot can assist the paramedic to turn over, feed, disinfect the patients. With the rapid development of mobile nursing robots, some of the mobile nursing robots will replace the paramedic to complete the majority of nursing jobs. The multi-functional nursing robot has two arms, a torso and a head. Robot’s arms can provide greater torque so that it can hold the patient. A variety of sensors are installed in robots including visual sensors, auditory sensors, and olfactory sensors. These sensors can effectively improve the nursing ability of the robot, and reduce the workload of the paramedic.

3. RESEARCH STATUS OF NURSING ROBOT

Since 1940, the first-generation model of the nursing robot has been invented, but it didn’t have specific functions such as nursing services. After 40 years, the nursing robot had some functions of nursing and assisting [13]. In 1990’s, a number of countries conducted in-depth study on nursing robot. Researchers have developed some nursing robots. At present, the three most important categories of nursing robots are independent nursing robots, rehabilitation nursing robots bed and multi-functional mobile nursing robots.

3.1. Independent Nursing Robot

Independent nursing robot mainly nurses the hygiene of patient. A company developed the intelligent nursing robot called XFCS-A, which is shown in Fig. (1). After the defecation of the elderly or long-term bedridden patients, this robot can clean the excreta. The XFCS-A mainly includes the collector and the control box. The collector is connected with the box through the catheter. When the patient defecates, the paramedic places the collector in the patient’s private position, and the excreta is sucked into the collector, then it will be deodorized. The patient’s buttock can be washed by warm water, dried by warm breeze and purified by negative ion so that the odor can be removed. The independent nursing robot can be used in the hospital and home. This nursing robot has the characteristics of convenience, safety and reliability.

A nursing robot “ROLA” is developed by National Chiao Tung University, it can achieve the “wherever” care for the elderly daily life [2]. The patient wears real-time human identification system. If the patient has an accident at home, with the help of the automatic wireless network communication system or 3G mobile phone, ROLA will automatically send the distress signal and the scene image to the family’s mobile phone, and immediately take the necessary rescue. Equipped with radar rangefinder, ROLA can detect and identify indoor furniture location. So, it can realize the functions of autonomous obstacle avoidance. ROLA has the speech recognition and natural dialogue function.

In 2005, the Toshiba of Japan developed the “company” and “recognition”, two series of home nursing robot [2]. These two nursing robots have a lovely appearance and full body. By building multiple microphones and using an advanced image, these two nursing robots can understand operator’s commands and automatically follow the operator’s function. These two nursing robots can also identify whether the surrounding environment is dangerous, thereby reminding the operator, and the nursing robot itself will start calling for help. These two robots are small and easy to carry. They are the little assistants of children and the elderly.

In 2013, Japan’s Panasonic Company produced an intelligent robot to assist nursing workers, called HOSPI-R. Its appearance is shown in Fig. (2). This robot can transport medicines under 20Kg once a time, at a speed of 1m/s in maximum. This robot equipped with a rechargeable battery, can work continuously for a week. Because the HOSPI-R possesses plenty of functions and intelligent qualities, the designer particularly pays attention to its safety and stability. The HOSPI-R provides the opening measures of smart card, so this robot can open the door to remove the drug when the paramedic uses the smart card. In addition, in order to ensure the safety of the medicine-transporting process, the robot is designed to store liquid and solid drugs differently. When the HOSPI-R intelligent drug delivery robot accelerates or stops, there is a corresponding buffer device to avoid the drugs or
liquid spill. In addition to ensuring the safety of drug transport, the efficiency of its transportation is also paid more attention. Equipped with sensors, this robot can present the map of the hospital. So, it can effectively avoid obstacles and pedestrians. At the same time, this robot can send the information of robot's location to the control center so that the control center can monitor and record its position at any time [14].

A modular symmetrical transport nursing robot and the bidirectional transport method of this robot are invented by Yanshan University, which is shown in Fig. (3). The transport module includes the lower transmission assembly and the upper transmission components. The lower transmission components include the walking machine frame, motor, the tension wheel, a walking driven cog belt wheel and synchronous belt. The upper drive assembly includes the parallel arranged on both sides of the board and the second motor. The second motor is connected with the driving gear and meshed with the drive gear wheel. The wheel engaged with the driven gear, the driving roller, two tensioning rollers arranged in parallel. The two lateral tension rollers are arranged at the bottoms of both sides of the board and in parallel with the active roller. This robot can realize the patient transferring between the bed and the stretcher vehicle transport. So, it can reduce the labor intensity of medical personnel and avoid the traditional way of transport which brings secondary damage to the patient in the transport process [15, 16].

![Fig. (3). Structure of a bidirectional transport robot.](image)

### 3.2. Rehabilitation Nursing Robot Bed

At the end of the last century, some developed countries began to focus on the study of rehabilitation nursing robot bed. The most representative companies are the United States Metrocare Company, Devicelink Company, Japan’s Panasonic Electric Company and Paramountbed companies. They are international industry leader in rehabilitation nursing robot bed.

A rehabilitation bed is designed by Metrocare company. It can support patient’s back and reduce the labor intensity of the paramedic. The company designed the functional bed board based on the principles of ergonomic planning [17].

The United States Device link invented the nursing bed, which combines bed with a wheelchair. The nursing bed can be transformed from a bed into a wheelchair, and vice versa. This is suitable for the long-term bedridden patients [18].

Paramount is the world’s largest manufacturer of medical bed [19]. This company developed a rehabilitation nursing robot bed called the Gakusho series, which is shown in Fig. (4). The back and knee joint of Gakusho can rotate simultaneously. It can effectively prevent bedsores and reduce the patient’s position deviation. The movements and the bending angle of back or knees of this nursing robot bed can be adjusted automatically.

![Fig. (4). Gakusho Z, Paramount, Japan.](image)

In recent years, China has made great progress in the rehabilitation nursing robot bed. Li et al. invented a multi-functional nursing robot bed, which is shown in Fig. (5). The nursing robot bed is divided into three horizontal boards [20]. These horizontal boards can be turned by the hydraulic cylinder, so that it makes the patient stand up. In addition, these horizontal boards consist of four longitudinal boards, which is driven by the hydro-cylinders. It can help the patient bend his knees or keep his back upright. The issue of defecation can be easily solved on condition that a toilet is set under the bed. Compared with the previous type, the needs of the vegetable can also be met. This nursing robot bed can help long-term bedridden patient to meet the needs of sitting, turning, eating, reading and writing, entertainment and other aspects.

![Fig. (5). Working principle of multifunctional nursing robot bed. CN201210013875.6.](image)

Li et al. invented a multi-functional nursing robot bed, which is shown in Fig. (6). It adds a number of functions and the mechanical structure to improve its stability and safety.
The multi-function nursing robot bed includes the back-supporting unit, the turning over unit of body, the excrement collecting unit, the curved leg unit and the bed unit [21]. The starting unit includes the straight putter, the back-supporting bar, the wire rope, the wire rope guide tube, the movable bed board, the back-supporting plate, the guide groove, the connecting rod, the straight putter fixed block and the slider. The bed unit includes the bedside guard, the bed tail guard, the guard rail and the operation panel. The bed unit is connected to the starting unit, the turning unit, the excrement collecting unit and the crank unit. The turning unit connects the back unit to the forth unit, and the turning unit is connected to the packing unit and the crank unit respectively. This nursing robot bed makes it possible for the patient to get self-nursing so that the nursing efficiency can be improved.

A rehabilitation nursing robot bed is developed by Shanghai University of Engineering Science [11]. It serves for the elderly, the disabled, long-term bedridden patients and patients with chronic diseases. The nursing robot bed can help the patient support his back, bend his legs, turn himself over, and go to toilet. As is shown in Fig. (7), this rehabilitation nursing robot bed provides patients with two operation modes. In the first mode, patient can control the bed by pressing the buttons on both sides or using a remote-control device. The second mode is performed by PC monitoring system. The function of the rehabilitation nursing robot bed is complete, safe and comfortable. It is easy to operate and can meet the daily requirement of the elderly and the disabled. In addition, the rehabilitation nursing robot bed has the office table and dining table. The table board can be overturned. The patient can have meals and handle some businesses. And a camera can also be placed on the table board, which facilitates the nursing staff and the family of the patient to check the patient’s condition.

He et al. designed a combined nursing bed, which is shown in Fig. (8). This nursing bed is similar to the patent CN201610815606.X. The moveable backrest is installed on the fixed bed body, and the wheelchair is setup at the rear of the moveable backrest. The wheelchair is made up of three rectangular boards, the wheelchair supports the driving component. When the nursing bed runs, the three rectangular boards are driven by the driving component, and pivot around the rotary shafts, so that the bed can be transformed into the wheelchair. The wheelchair can be separated from the bed body. In the separating and combining process, the patient can realize the transformation between the wheelchair and the bed easily. The transferring process does not consume great physical energy of the nursing staff, and the patient will not suffer from redundant discomfort [22].

In the practical application of the robot nursing bed, it cannot solve all the cleaning for patients. A nursing robot bath cabin system is invented by Henan University of Science and Technology. The core components of the nursing robot bath cabin are bathing system and the robot. The nursing robot bath cabin system can assist human in standing and provide some cleaning services. The robot basically contains that auxiliary standing mechanism, rubbing mechanism and head-washing mechanism. According to the design objectives of the nursing robot, the overall program design of the nursing robot was proposed, which is shown in Fig. (9). With the help of the standing system, the nursing robot can help the operator to convert from the standing to sitting. The design of the bathing cabin will be directly influenced by the body size of operators and the space. When the servo motors drive the gears respectively, the auxiliary supporting system can realize the longitudinal and transverse spin rotation. The backrest lifting frame, the lifting frame, the supporting handrail armrest and the seat bracket are installed vertically. When the electric putter and foot floor in the horizontal di-
rection are moved, the bathing in sitting posture will be finished by the coordinated movement of vertical axis and horizontal axis of the convertible [23].

A medical robot electric nursing bed is shown in Fig. (10). It comprises the bed body and medical robot. The upper body and the lower slide block are fixedly arranged on the lower trunk of the robot. The gear and the slider are installed in the slide block. The robot can slide on the bed. The tail of the bed and the fixing bed legs are connected with the motor, and drive the lifting platform. The bed equips with the conveying mechanism, and it includes the basin device to the bedpan and the lifting platform. The massage mechanism, the pillow board lifting device, the backrest lifting device and the toilet sliding device are all connected with the bed body. The nursing bed can automatically rotate patient, do some massage and change the bedpan. The patent has the advantages of multiple functions of medical treatment and nursing, and it can reduce the workload of nursing staff [24].

Kawasaki heavy industry filed a patent on the nursing bed, which is shown in Fig. (11). This nursing bed includes the fixed members and the movable members. The operator can lie in the bed board formed by the fixed members. The movable members can form a moving bed board. The fixed members have many elongated sections that respectively extend in the lateral direction or the longitudinal direction. The movable members can be moved between intervals formed by elongated sections, which makes the fixed board lift up. The movable members can be operated in the lateral direction and the longitudinal direction. The patient lying in the bed can turn over effortlessly [25-27].

Zhang et al. invented a nursing bed, which is shown in Fig. (12). This nursing bed has two-bed structure and right trapezoid framework. The two wheels of the bed are driven differently. The part which supports the back is located at the rear of the right-angled trapezoid. The part which supports the legs is located in the front and sides of the right-angled trapezoid. The lower board which supports thigh is hinged with the lower board which supports shank. The turn-over parts locate between the back-supporting part and the leg-supporting part. The part of pedal lifting is attached to the
lower board which supports shank, to meet the requirements of different groups with different pedal positions. The hip-supporting part is located in the center of the right-angled trapezoid. And the toilet is installed under the hip-supporting board. The toilet can be lifted and the toilet lid can be turned off. The nursing bed can not only be used as an intelligent tool for transportation, but also can meet the requirements of diverse postures and requirements for daily care in families and hospitals [28].

![Fig. (12). Nursing bed CN201110239654.6.](image)

The robot nursing bed is shown in Fig. (13). The bed body includes the fixed L-shaped frame and the movable bed frame. The space between the fixed bed frame and the movable bed frame is used to store the motor drive mechanism and the wheelchair. The movable bed can be opened or closed by the rotation of the motor, and the wheelchair is detachable. The motor can be controlled by the limit switch and the control device, so that the movable bed can be rotated. This robot nursing bed is reliable and easier to control, and it has the advantages of small size, simple structure and low failure rate [29].

![Fig. (13). Structure of robot nursing bed CN201620022589.X.](image)

### 3.3. Multi-Functional Mobile Nursing Robot

The independent nursing robot or nursing bed cannot meet the increasing nursing needs, because of the narrow range of the application. As a result, the researchers develop the mobile nursing robot.

In 1980’s, Japan developed a nursing robot called the “MEIKONG”, and this robot can help the patient get out of bed by themselves. And the patient can also be seated in the wheelchair so that the robot can take the patient wherever they want to go. In 2007, a mobile multi-functional nursing robot called the “TWENDY-ONE” is developed by Waseda University of Japan. Its appearance is similar to human’s appearance and it is illustrated in Fig. (14). It has a full range of mobile platform. The 13 sensors are installed in the robot’s hands so that some subtle movements can be performed better. Figure 15 shows that the TWENDY-ONE has only four fingers, and the six-axis force sensors are installed at its fingertips. The soft skin is applied to the palm surface so that the touch is more similar to the human body, and the distribution pressure sensors are installed in the palm surface. Its arm is shown in Fig. (16). This arm, which is equipped with the torque motor, can pick or lift the patient. The TWENDY-ONE is a complex non-linear humanoid nursing robot. The TWENDY-ONE, equipped with a high power output driver, can flexibly combine the high power output with the mechanically impedance mechanism [30-32].

![Fig. (14). TWENDY-ONE, Waseda University, Japan.](image)

![Fig. (15). TWENDY-ONE’s fingers.](image)
A robot called RIBA makes it possible for the patient to get out of bed, so that the patient can hold the wheelchair. However, its functional limitations prevented this robot from being commercialized. Thus, the RIKEN-TRI Collaborative Center for Human-Interactive Robot Research (RTC) developed a new robot named RIBA-II, which is shown in Fig. (17), and there are 10 degrees of range in its arm. The power and new feature are added in the RIBA-II to overcome the limitations of first generation. The RIBA-II is a dual-arm robot, becoming the first robot to finish the clinical test. There are some new joints in this robot, which is shown in Fig. (18a). The two waist joints and the power-assisting springs are installed in this robot. RIBA-II can adjust basic action according to the height and weight of patients. Initially, the robot determines location by touch, and then it gives a command to finish the movement and adjustment. The control of movement, based on touch, is finished by the mechanical model of a human that is illustrated in Fig. (18b). The mathematical model of safety assessment is built on posture, force, velocity, acceleration, comfort level and sign of patients. The posture of patients can be analyzed by the mathematical model and the mechanical model in real-time so that the possible danger can be predicted in target track. The track can also be corrected in real-time. Meanwhile, BIRA-II can maintain stable posture thus the maximum contact pressure and shear force are less than the bearing capacity of patients. The advanced skin sensors, individually developed and researched by teamwork, are installed in RIBA-II. This robot can perceive the state of patients, so that the skin sensor can ensure the safe touch with patients. The smart rubber sensors, made entirely out of rubber, are the first capacitance-type tactile sensors. The sensors are installed in the robot’s arms and chest, so that its action can be accurately guided. RIBA-II has a physical examination for patients, so that the robot can ensure the health and safety of patients [33].

The PR2 was designed by the Georgia Institute of Technology. There are seven joints in two arms, and there is a pair of manipulator at the rear of the arm. The joints and other units of the PR2 are shown in Fig. (19). There are four wheels installed at the bottom of PR2. Components of the robot are mobility base, torso, manipulator, tray and sensor carrier with sensors. This robot is driven by four wheels. Each wheel’s orientation and rotational speed can be set individually. The wheel driver is installed in legs to ensure safety and stability during manipulation. The base also includes the Li-Io battery pack, laser scanners and a PC for navigation tasks. The size of the base is mainly defined by the required battery space. It has been extended by 120mm to increase the work area so that the manipulator can reach the floor. Special attention was paid to the mounting of the arm on the robot torso. The result is based on simulations for finding the ideal work space covering the robot’s tray and the floor. The quick-change system allows to attach different manipulators, robotic hands or other tools to the arm. The 7-DOF Schunk Dexterous-Hand has tactile sensors in its fingers so that some complex gripping actions can be performed [34].

Georgia Institute of Technology also has designed a nursing robot to help patients clean up their bodies, which is shown in Fig. (20). A statically stable mobile manipulator is used in this study. It is assembled at the Healthcare Robotics Lab, and to perform the cleaning task. The designer paid attention to designing these robotic arms, which have actuators with low mechanical stiffness. The arms are made up of two 7-DOF anthropomorphic arms with series of elastic plastic, and the wrists are equipped with 6-axis force/torque sensors. They designed a behavior for a robot to perform autonomous wiping, and an operator-selection interface that allows the operator to select the desired area for the robot to clean. The robot can clean most of the debris (> 96%) from the upper arm, the forearm, the thigh, and the shank. This is the first step towards developing a robot that can autonomously perform bed baths for patients [35].

A home-care robot called “MARY” is developed by Tohoku University, which is shown in Fig. (21). MARY has the 360 degree-panoramic camera and the color-camera as the eye-in-hand system. The stereo vision system of MARY is made up of the cradle head and a pair of cameras. The arm can carry an 8Kg payload. The gripper is equipped with a touch sensor on its fingertip and it has an optical sensor between the fingers. The robot is powered by lead-acid batteries. The operating time for intensive use is around two hours. The frame of the robot is covered with foam casing so that the robot and environment can be protected in the case of collision. A tray, made of aluminum, is attached to the frame and equipped with proximity switches [36]. A colored paper on the tray is used as the background for image processing and it can be easily changed to test different colors.

A transfer nursing robot is designed by the Japanese Horse Shilu Corporation [37]. It is used to reduce nursing burden. They designed the behavior for this robot to perform nursing and moving, and enabled it possible to make the operator walk and stand by themselves. The robot has three parts. The part of M1 is the driving department. The driving part is installed on the part of M2. The roll on the lifting, is
installed on the part of M3, which is the operating part. These parts are shown in Fig. (22). A pair of arm-rolls and the auxiliary part are installed on the main part of it. The rotation members are arranged on the rotation body of the auxiliary part and the arm can support the rotation members in holding, for the purpose to ensure the stability and safety.

A nursing robot was developed by Fuji Machinery Co., Ltd. in 2014. And it is similar to their previous patent, developed in 2013. However, this patent is more perfect than the one before, which is shown in Fig. (23). The robot is made up of three parts: the holding part, the mobile operation part and the correction part. The holding part and body ensure the nursing in the case of operating. Furthermore, the holding part can autonomously record and store the patient’s posture from sitting to standing. The holding part is controlled by the operator, who uses the mobile operation part to change the posture of the patient. The correction part makes tiny adjustment, based on the previous stored posture. The movement path of robot is constantly corrected by these three parts so that the robot can efficiently and sustainably complete finishing the nursing work [38-40].
The ideal posture of the forearm can be maintained in the seat, and is installed in the holding part [41]. The change of the patient’s posture is shown in Fig. (24), and its movement is controlled by three parts of the robot.

Korean Institute of industrial technology developed an auxiliary nursing robot, which is shown in Fig. (25a). The nursing robot for moving patients is made up of two main parts: the supporting subject and the clamping element [41]. The supporting subject supports the top half of the patient. The clamping element can protect the patient and rotate the supporting subject. There is a strut placed under the supporting subject to adjust the height of the robot. The researchers designed a behavior for this robot to perform transforming and transporting, which makes it possible for the patient to maintain the most comfortable posture, and the working condition is shown in Fig. (25b). The robot minimizes the physiological and psychological pressure of the nursing stuff so that the heavy pressure can be relieved and the administrative expense can be reduced.
A nursing robot is invented by Harbin University of Science and Technology [42]. The robot consists of the auxiliary standing part, the auxiliary walking part and the manned walking part. The robot is shown in Fig. (26). The auxiliary standing part is made up of the slide board and the supporting frame. The supporting frame which supports the back is connected with the base-plate by the lead screw, and the slide board is installed in the sliding rail of the baseplate. The auxiliary walking part is composed of the thrust rod of the seat plate, the sliding rail and the supporting rod of the armpit. The thrust rod of the seat plate is connected with the sliding rail by the slider, and the supporting rod of the armpit is installed in the supporting frame. The manned walking part is made up of the wheels and the seat plate. The auxiliary standing part is connected with the auxiliary walking part by the lead screw, the polishing rod and baseplate. The auxiliary walking part is connected with the manned walking part by base-plate, the slide plate and the seat plate. The nursing robot, by the movable thrust rod, can autonomously adjust the different height of patients.

Fig. (25). Mobile robot for patient care CN201380001648.4.

A double joint nursing robot is invented, which is shown in Fig. (27). This robot is designed to help the paralytic patient to regain walking ability [43]. Two motors are installed in the front of the baseplate. There are two sets of three-claw-type wheel frames at the rear of the baseplate for increasing the supporting area of the base-plate so that the robot can be used in narrow space. The single column, installed in the middle of the baseplate, is made up of two flexible joints which imitate human joints. The lower joint is the unit of knee joint, and the upper joint is the unit of hip joint. There are chest and arm on the top of the single column. Initially, the double joints arm of the robot, driven by the control system, encircles the waist of patients so that the patient’s body can be tilted. Finally, the double joints of the robot will straighten so that the patient can stand the base-plate by themselves.

Fig. (26). Robot for nursing service CN201520432677.2.

Fig. (27). Double joint nursing robot CN200610000233.0.

Tai-Kang Han invented a nursing robot, which is shown in Fig. (28). The wheelchair is reasonably combined with the bed so that this nursing robot can help the patient walk and sleep. The supporting assembly, installed in the support structure, includes a seat, a backrest, a leg plate, a foot plate, a first driving device and a second driving device. The seat is attached to the supporting structure [44]. The first rotation shaft connects the backrest with the other side of the seat; however, the leg plate is connected with the opposite direction of the backrest by the second rotation shaft. The foot plate is connected with the rear of the leg plate by the third rotation shaft. The first driving device is installed at the bottom of the seat, and both sides of the driving device are connected with the backrest and
the leg plate so that the device can drive them. The foot plate is driven by the second driving device, which is installed at the bottom of the leg plate. The patient can move it to any place without any other person’s help.

Recently, researchers have inclined to study home-nursing robots which belong to the multi-functional mobile nursing robots. These robots are more specialized than other nursing robots. The inventor successively developed nursing robots for shampoo [45], for diet [46], for transporting drug [47], and multi-functional home-nursing robots [48, 49].

A nursing robot for shampoo is invented by Li et al., which is shown in Fig. (29). This robot solves the safety control problem of the cleaning device on the existing shampoo robots, and it also guarantees the cleaning of the user’s home [45]. This nursing robot adapts to any type of operator, and ensures the cleaning effect of operator’s hair. The cleaning device is installed within some sensors to detect the position of the human head, and the moving mechanism is controlled by the sensing signal.

University of Shanghai for Science and Technology invented a dietary nursing robot to feed the patients in 2017 [46]. Laser transmitter and laser sensor are installed in this nursing robot. The laser transmitters are positioned at the patient’s head for emitting a laser signal. The laser sensors are positioned at a table with multiple bowls, and it receives a laser signal and generates a corresponding sensing signal. According to the sensing signal, the robot feeds the food to the patients in the corresponding bowl.

In order to increase the amount of drug delivery and reduce the labor intensity of nursing staff, Wu et al. invented a nursing robot for transporting drugs [47]. An intelligent wheeled robot chassis and a column are installed in the middle of this robot. The rotatable mounting frame is installed at the top of the column, and the frame consists of six sides and a bottom surface for placing various types of medication. Robot structure and top view of the frame are shown in Fig. (30).

In recent years, the multi-functional home-nursing robots are generally similar in structure, and it mainly relies on the sensor and the specific controller to nurse the patients. A home-nursing robot is invented. It includes a shell, a head
and a smart bracelet. The specific function is equipped with a heating tube and a dispenser. Thus, the drugs can be accurately rationed according to the needs of the patient and the elderly [48]. Guo invented the multi-functional nursing robot equipped with a monitor and a human infrared detector. This robot can measure the temperature of the human body in real time and provide the infrared treatment scheme to patients [49]. Dual-arm nursing robots have the poor flexibility and the structure is complicated. In order to solve such problems, Hebei University of Technology invented a width-adjustable self-retraction arm mechanism for nursing robots [50]. This mechanism is simple and compact, and it can automatically adapt to any type of nursing robots.

Overview and classification of nursing robots are shown in Table 1.

4. KEY PROBLEMS ON APPLICATION OF NURSING ROBOT

Nursing robot, as a complete set of robot systems, is facing the current problems on three aspects: the design of mechanical structure, the issue of control and humanization.

The mechanical structure plays a vital role in realizing the whole function of the robot, and its stability and safety could be directly affected by the reasonability of structure. In the practical application, the multi-functional mobile nursing robot should finish an action which picks up the patient, therefore, the robot is provided with greater power by the torque motor. This motor could save energy, reduce volume and weight; however, the cost of the motor will increase. Additionally, when it comes to the design of the double-arm robot, its arm-moving path plan is difficult and the development progress is slow. In terms of the future development of the robot, the issues of quality, cycle and cost exist in the mechanical structure. To sum up, the nursing robot should be more reliable and safer in the design structuring aspects.

At present, there are still problems in the aspect of controlling robot. In order to improve the intelligence of the nursing robot, a variety of sensors are installed. The different information collected by these sensors, is analyzed by the controller, so that the judgement can be informed by the controller. The stability of the controlling system will be tested whether the system informs a series of correct instructions when the robot realizes some functions on the coordination between these sensors and the controller.

The humanization design is essential because the nursing robot belongs to service robot, and its main service targets and operators are people. The nursing robot can be controlled by speech recognition or gesture manipulation when the patient’s action is inconvenient. The nursing robot, equipped with cameras, can achieve remote monitoring of patient so that the camera can shorten the distance between patients and nursing stuff. The principle of humanization can help nursing robots strengthen its serving ability for the patient and improve efficiency for assisting the nursing stuff. Therefore, the designer should also pay attention to the principle of humanization on the basis of the problem on structure and control. With the rapid development of all disciplines, the designer can combine the advanced technology with the nursing robot, which improves the ability for nursing the patient.

<table>
<thead>
<tr>
<th>Robot Type</th>
<th>Publication, Year</th>
<th>Characteristic</th>
<th>Code or Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yanshan University, 2016 [15, 16]</td>
<td>Modular symmetrical transport robot, Reduce the labor intensity of nursing person</td>
<td>CN201611218398.1, CN201611218489.5</td>
<td></td>
</tr>
<tr>
<td>National Chiao Tung University, 2015 [2]</td>
<td>Automatically send the distress signal, Install radar rangefinder to autonomous obstacle avoidance, Speech recognition and natural dialogue function</td>
<td>ROLA</td>
<td></td>
</tr>
<tr>
<td>Suyocon Company, China, 2013</td>
<td>Realize independent nursing, Wash buttock and collect deodorize, Automatic identification</td>
<td>XFCS-A</td>
<td></td>
</tr>
<tr>
<td>Panasonic Company, Japan, 2013</td>
<td>Rechargeable battery, Monitor and drug storage box, Load 20kg and speed of 1m/s in maximum</td>
<td>HOSPI-R</td>
<td></td>
</tr>
<tr>
<td>Toshiba Company, Japan, 2005</td>
<td>Multiple microphones, Advanced image and vision device, Small size to easily carry</td>
<td>References</td>
<td></td>
</tr>
</tbody>
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Table (1) contd....
<table>
<thead>
<tr>
<th>Robot Type</th>
<th>Publication, Year</th>
<th>Characteristic</th>
<th>Code or Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beihua University, China, 2016</td>
<td>Realize self-nursing</td>
<td>CN201610815606.X</td>
<td></td>
</tr>
<tr>
<td>He and Sheyang, 2016</td>
<td>Combine bed with wheelchair, Wheelchair can be separated from the bed body, Conversion process is simple</td>
<td>US9295596</td>
<td></td>
</tr>
<tr>
<td>Qing J.H., 2016</td>
<td>Fixed L-shaped frame and movable bed frame</td>
<td>CN201620022589.X</td>
<td></td>
</tr>
<tr>
<td>Henan University of Science and Technology, China, 2015</td>
<td>A nursing robot bath cabin system, Assist patient to standing, rubbing and shampoo, Auxiliary standing mechanism,</td>
<td>Master's Thesis</td>
<td></td>
</tr>
<tr>
<td>Shanghai University of Engineering Science, 2015</td>
<td>Two operation modes, Automatically support patient back and leg, Office and dinner function</td>
<td>Master's Thesis</td>
<td></td>
</tr>
<tr>
<td>Li et al., 2012</td>
<td>Three horizontal boards consist bed, Power by hydraulic cylinder, Solve the issue of defecation</td>
<td>CN201210013875.6</td>
<td></td>
</tr>
<tr>
<td>Nanchang University, China, 2011</td>
<td>Two-bed structure and right trapezoid framework, Back-supporting part, leg-supporting part and hip-supporting part</td>
<td>CN201110239654.6</td>
<td></td>
</tr>
<tr>
<td>Shen Y.Y., 2005</td>
<td>Conveying mechanism, Backrest lifting device, Toilet sliding device</td>
<td>CN200510046143.7</td>
<td></td>
</tr>
<tr>
<td>Metrocare Company, 2010</td>
<td>Reduce the labor intensity of the paramedic, Production’s size based on the principles of ergonomic planning</td>
<td>References</td>
<td></td>
</tr>
<tr>
<td>Devicelink Company, United States, 2005</td>
<td>Combine the bed with wheelchair, Nursing bed can transform from a bed into a wheelchair, and vice versa</td>
<td>References</td>
<td></td>
</tr>
<tr>
<td>Paramount Company, Japan, 2014</td>
<td>Reduce the patient's position deviation, Automatically adjust bed movements</td>
<td>Gakusho Z series</td>
<td></td>
</tr>
<tr>
<td>Guo X.F., 2018</td>
<td>Smart bracelet, Heating tube and dispenser</td>
<td>CN201711023613.7</td>
<td></td>
</tr>
<tr>
<td>Li et al., 2017</td>
<td>Shampoo head nursing robot, Adapt any shape of head of operators</td>
<td>CN201710793011.3</td>
<td></td>
</tr>
<tr>
<td>University of Shanghai for Science and Technology, 2017</td>
<td>Laser transmitter, Laser sensor, Automated feed to patients</td>
<td>CN201710128312.4</td>
<td></td>
</tr>
<tr>
<td>Wu Y.C., Chen J., 2017</td>
<td>Intelligent wheeled robot chassis, Rotatable mounting frame</td>
<td>CN201720018358.6</td>
<td></td>
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Table (1) contd....
<table>
<thead>
<tr>
<th>Robot Type</th>
<th>Publication, Year</th>
<th>Characteristic</th>
<th>Code or Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harbin University of Science and Technology, 2015 [42]</td>
<td>Auxiliary standing part and manned walking part, Supporting frame, Autonomously adjust the different height of patient</td>
<td>CN201520432677.2</td>
<td></td>
</tr>
<tr>
<td>Tokai Rubber Industries, Japan, 2015 [33]</td>
<td>Lift people (weighing up to 80kg) off the floor and onto a bed, Arms and hands are as soft as possible</td>
<td>RIBA-II</td>
<td></td>
</tr>
<tr>
<td>Japanese Horse Shilu Corporation, 2014 [37]</td>
<td>Driving department (M1), Driving part (M2), Operating part (M3)</td>
<td>CN201480056908.2</td>
<td></td>
</tr>
<tr>
<td>Fuji Machinery Co., Ltd., 2014 [38-40]</td>
<td>Record and store the patient’s posture from sitting to standing, Correction part makes tiny adjustment based on the previous stored posture</td>
<td>CN201380076990.0, CN201380072426.1, CN201480077584.0</td>
<td></td>
</tr>
<tr>
<td>Tohoku University, 2013 [36]</td>
<td>360 Degrees panorama camera, Stereo vision system, Lead-acid batteries</td>
<td>MARY</td>
<td></td>
</tr>
<tr>
<td>Korean Institute of Industrial Technology, 2013 [41]</td>
<td>The supporting subject and the clamping element, Minimize physiological and psychological pressure of the nursing stuff</td>
<td>CN20138001648.4</td>
<td></td>
</tr>
<tr>
<td>Ulrich Reiser et al., 2009 [36]</td>
<td>7-DOF Schunk Dexterous-Hand, Laser scanners and PC, Li-Io battery pack</td>
<td>Care-O-bot R3</td>
<td></td>
</tr>
<tr>
<td>Waseda University, Japan, 2007 [30-32]</td>
<td>Humanoid robot and soft skin, 13 Sensors are installed in the robot’s hands, Six-axis mechanical sensors is installed in its four fingertips</td>
<td>TWENDY-ONE</td>
<td></td>
</tr>
<tr>
<td>Liu Feng, 2006 [43]</td>
<td>Two motor-driven, Help the paralytic patient to recover walking</td>
<td>CN200610002233</td>
<td></td>
</tr>
<tr>
<td>Tai-Kang Han, 2004 [44]</td>
<td>Help the patient in walking and sleeping, The patient can move to any place without any other person’s help</td>
<td>US674220 6</td>
<td></td>
</tr>
<tr>
<td>Georgia Institute of Technology, 2009 [34]</td>
<td>Seven joints in two 4-DOF arms, 3-DOF sensor head, Tilting sensor range finder</td>
<td>PR2</td>
<td></td>
</tr>
<tr>
<td>Georgia Institute of Technology, 2010 [35]</td>
<td>Two 7-DOF anthropomorphic arms, 6-Axis force/torque sensors, Cleaning range is greater than 96%</td>
<td>IRB</td>
<td></td>
</tr>
</tbody>
</table>

**CONCLUSION**

Nursing robots integrate various actuation mechanisms, sensors, and control strategies with the sole purpose of improving patients' nursing condition. This paper concludes the current challenges in terms of reliability, safety, and intelligence by classifying, contrasting and analyzing various nursing robots. There is still room for improvement and optimization of all these issues, therefore, more patents and experiments on the nursing robot will be invented and re-
searched in the future work. This paper functions as a meaningful reference for the development of nursing robots and nursing career. We will focus on reviewing and discussing control strategies and algorithm of the nursing robot in the future study.

CURRENT & FUTURE DEVELOPMENTS

As the number of elderly people is increasing, and most of the elderly are accompanied by the pain of the disease, they need the companionship and care of the nursing staff. However, the traditional modes of nursing have been unable to meet the nursing needs of all elderly people. Therefore, the development and research of nursing robots is crucial, and it can make great contribution to society and the country, then relieve social pressure.

After the above discussion, the nursing robot is developing rapidly, and the research of the nursing robot, carried out in Europe and America, is earlier than other countries. The research, development and application of the nursing robot have reached the world leading level although the research of robot started relatively late in Japan. The nursing robot is a combination of multi-disciplines, therefore, there are many problems to be solved. New challenges in the development of the nursing robot arise concerning how to reduce its manufacturing costs, ensure its safety and reliability and improve its level of Human-Machine interaction. Additionally, the nursing robot can fix the physical damage of patients, and how to treat the patient with psychological mental illness still need to be studied.

At present, the nursing robot complies with the development of the times and accords with the practical needs of the modern society, and it represents the advance of medical technology. Similarly, the service robot, as an important branch in the direction of modern robots, its number will exceed industrial robots in the near future. Nursing robots, part of the high-tech service industry in the new century, will effectively promote the country’s economic growth and become the sunrise industry in the world. The development of service robots is a great opportunity for the intellectual technology industry in the world, and this industry has important strategic significance for improving the competitiveness of the country.

LIST OF ABBREVIATIONS

DOF = Degree of Freedom
RTC = RIKEN-TRI Collaborative Center for Human-Interactive Robot Research

CONSENT FOR PUBLICATION

Not applicable.

CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

ACKNOWLEDGEMENTS

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