Chapter

Healthcare Robots and Smart Hospital Based on Human-Robot Interaction

Kazuhiko Terashima, Kazuhiro Funato and Takuyuki Komoda

Abstract

This chapter first introduces the research on next-generation care systems and stations that the author's group has actually conducted. Next, the development trends, challenges, and prospects for smart hospitals, which aim to improve overall hospital efficiency based on CPS technologies such as sensing, IoT, AI, and big data processing, in addition to robotics and control technologies, toward the realization of Society 5.0, are described. Third, the concept of the smart hospital and discussion will be explained to provide basic knowledge for its construction. Finally, future scope and conclusion will be described.

Keywords: smart hospital, health care system/station, human-robot symbiosis, health care robot, social robot

1. Introduction

Society 5.0 is a society in which humans can lead more comfortable and vibrant lives with the help of AI and robots [1]. This new type of society proposed in the Fifth Science and Technology Basic Plan in January 2016 includes the Internet of Things (IoT) [2], big data [3], artificial intelligence (AI), robots, and other cyber-physical systems (CPS) [4, 5]. The basic technologies are listed below. Along with the smart society and the smart factory, the smart hospital is one of the targets. Having established the Human-Robot Symbiosis Research Center at Toyohashi University of Technology in 2010, the lead author has been engaged in robotics research related to human-robot symbiosis, as well as research on next-generation nursing care systems and stations as a project of Japan's Ministry of Education, Culture, Sports, Science and Technology. The following robots are considered to perform major work processes for reducing care work and ensuring greater patient comfort: a patrol robot, an integrated transfer/transportation robot, an omnidirectional gait support robot, a power-assisted bed, a social media robot, and a comprehensive system for care scheduling and care. We have been conducting research and development of the station etc. Therefore, this chapter first introduces the research on next-generation nursing care systems and stations that the author's group has actually conducted. Next, the authors discuss the trends, challenges, and prospects for the development of smart hospitals that are

intended to optimize the efficiency of entire hospitals based on CPS technologies such as sensing, IoT, AI, and big data processing, in addition to robotics and control technologies, with the aim of realizing Society 5.0. The concept of a smart hospital is described, providing basic knowledge for the construction of smart hospitals.

2. Research trends and results of next-generation care station development

2.1 What is the next-generation care station

Figure 1 shows the main tasks in which robots could be used in nursing homes and hospitals. There are various types of tasks involved in assisting caregivers. However, it would be wasteful to introduce robots only for specific tasks if sufficient use were not made for those robots. It is necessary to clarify the position of robots in nursing care and daily life support, and to introduce robots and systems as a comprehensive system, taking into consideration the coordination of each task. In addition, showcasing of care systems and care stations that demonstrate the workflow of human-robot symbiosis and coexistence would be beneficial for future practical use. Although research on smart spaces and robot houses [6] has been undertaken in recent years, there have been few showcases for nursing care. They include the Ochanomizu University Ubiquitous Computing Experimental House (aka Ochahouse) [7], where sensors are embedded in the space and the residence is fully equipped with a sensing system, and the Human Residence House (C-PRH), where research is being conducted on optimization of the residential environment for the introduction of robots. In addition, SELF (Sensorized Environment for LiFe) [8], and robotic rooms are being studied, which are useful for the automation of nursing care [9]. However, unlike in an automobile factory, these systems are not intended to be completely unmanned. Rather, the goal is to create a comfortable and safe system conducive to cooperation and coexistence among medical personnel, patients, and robots. The
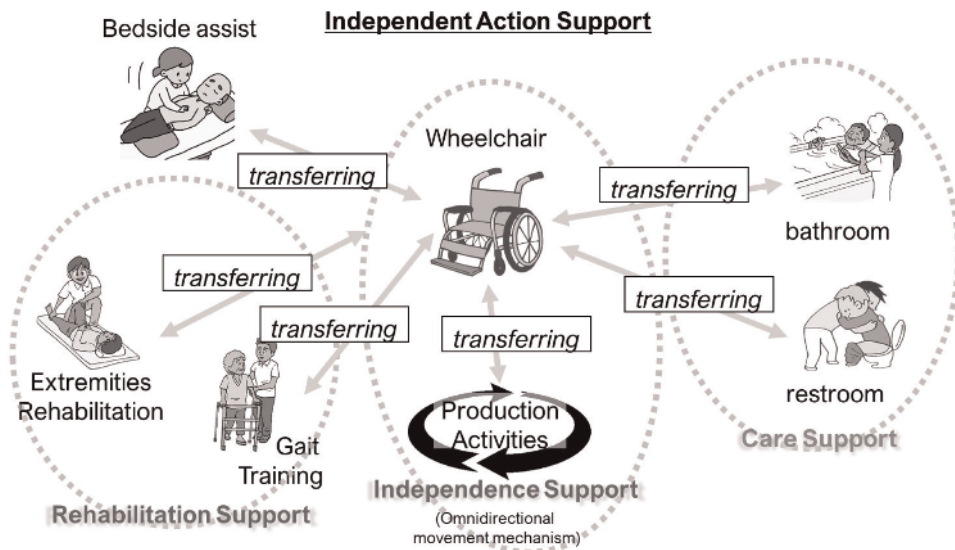

Figure 1.
Examples of major tasks for which robots may be used in nursing homes and hospitals. For example, support for independence, including rehabilitation and daily life support from the bedside.

Research Center for Human-Robot Symbiosis at Toyohashi University of Technology has been working on the project "Development of Next-Generation Nursing Care System and Station to Enrich the Super-aging Society," which was specially funded by the Ministry of Education, Culture, Sports, Science and Technology (FY 2012−2018). We have been conducting innovative and unique research and development with the aim of developing a system enabling the realization of high-quality services that provide a sense of healing and hospitality so that people can experience a sense of purpose in their lives. Our group's robot is distinctive in that it is not a fully automatic robot, but an assistive robot focused on human intention that is easy to operate and use virtually anywhere, giving a sense of security, and aiming for human-robot symbiosis. Therefore, we first introduce some representative care robots and care systems that have been researched and developed by the authors' group [10].

2.2 Hospital rounds robot Terapio and Patrol robot Kurumi

We are developing a mobile medical checkup robot that performs the two tasks of moving *things* and *information*. We have developed Terapio, a medical rounds robot that replaces the conventional rounds carts used by doctors and nurses during rounds in hospitals, and supports the transportation of medical tools and examination work (recording of medical data) (**Figure 2**) [11–13]. As a result of examining how to operate the robot as a medical robot, the need for omnidirectional movement was considered, especially for bedside maneuvering. Mechanisms capable of omnidirectional movement include the free-roller type, ball type, and caster type, typified by the omniwheel and the mecanum wheel. The free-roller type transmits power to the road surface by means of free rollers on the periphery of the wheel. Because of its simple structure, low cost, and relatively easy control, it is still used as a power source for general omnidirectional moving platforms. However, because of the free rollers, this mechanism has a low ability to go over bumps and traverse uneven terrain. In addition, vibration and noise problems may make it unsuitable for some applications. The DDSS (Differential Drive Steering System) (**Figure 3**) [14–16], a unique
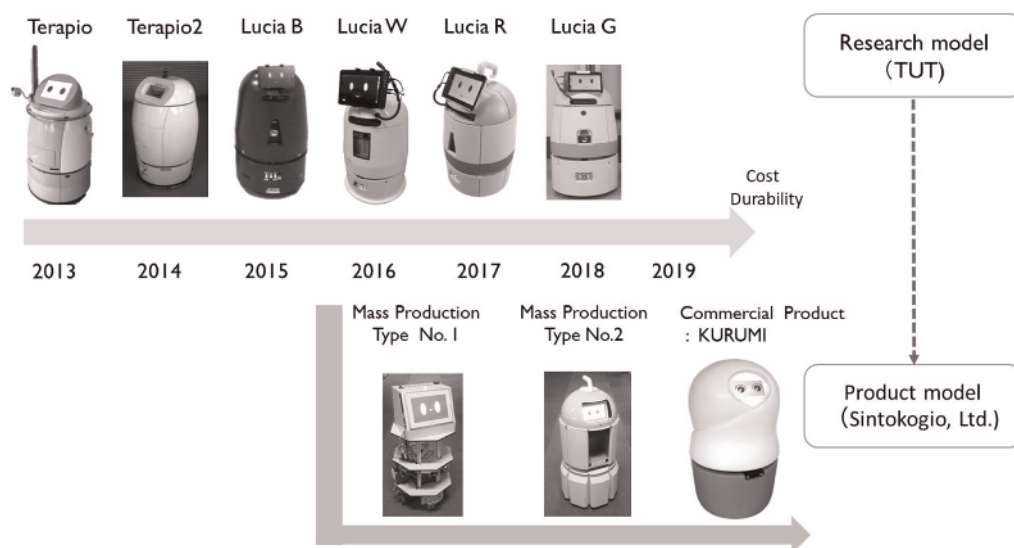

Figure 2.
Transition of mobile robots developed by the authors. The upper row shows basic research including Terapio, a medical round robot. The bottom row shows applied research for practical use including KURUMI.
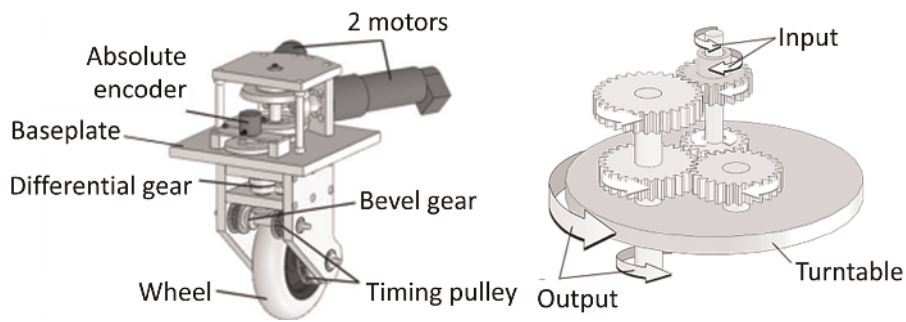
Figure 3.
Structural drawing of the DDSS developed by the authors, an omni-directional wheel that maximizes the efficiency of two motors and can move instantly in any direction.

differential drive steering mechanism developed by the authors, is used as the drive system for this robot and equipped with an omnidirectional movement function that is both quiet and has high performance over bumps. The main body of the robot is equipped with a range sensor that recognizes the environment in all lateral directions as well as forward and downward. The robot uses the range sensor to recognize the environment and has a tracking function to autonomously follow a specific person while avoiding obstacles. This eliminates the need to prepare map information and a travel plan in advance. The robot also has a ring-shaped power-assisted handle that can be operated accurately with a small amount of force when moving Terapio by direct touch to enable other people to position it at the bedside. The robot together with the object to be transported weighs approximately 80 kg. Without power assist, the user is subjected to a large load, but with power assist, the operation is possible with a small load of 10–20 N. In addition, it has a function that allows patients' personal information and vital data to be recorded and viewed, including past information, and at the nurses' station, it has a function that allows sending/receiving rounds data and managing all patient data by a wired connection to an information server. User authentication is provided to prevent unauthorized viewing and manipulation of rounds and patient data. The database is encrypted and cannot be deciphered by direct access. Terapio's overall integrated system can be switched by the supervisory controller to autonomous tracking mode, power-assisted mode, and consultation mode for different types of robot operations. As shown in **Figure 2**, in the Aichi Prefecture "Priority Research Project in Knowledge Hub Aichi" from FY2017 to FY2019, the Toyohashi University of Technology and Sintokogio, Ltd. and nursing home of the Tenryu Koseikai social welfare corporation were used as field test sites for practical use in cooperation with the private sector. The robot Kurumi was developed as a night patrol robot in a nursing home to manage people with dementia. It is based on Terapio's basic technology and is equipped with a function that enables it to move around the facility automatically and to contact caregivers after detecting a wandering person with dementia. The company is planning to commercialize the product.

2.3 Transfer and transportation integrated care robot

Until now, two types of nursing care equipment, a patient lift, and a wheelchair have been required to assist with transfers and transportation in the nursing care field. Therefore, we analyzed these processes and proposed and fabricated an omnidirectional power-assisted transfer/transportation integrated care robot that combines an

omnidirectional transfer mechanism and a power-assisted lift mechanism, with the aim of performing these tasks with a single robot (**Figure 4**) [17, 18]. A mechanism that can be transformed to the required size at the time of use was designed to enable use in the home. The minimum height is 1750 mm × 720 mm width × 1050 mm depth, and the maximum height is 2100 mm × 720 mm width × 1600 mm depth. Using the prototype integrated transfer/transportation care robot, a series of care actions were realized, including attaching a sling sheet to a patient in bed, lifting and lowering the patient in the lift section and moving the patient toward the seat, placing the patient in the seat, and transporting the patient in the transfer section of the integrated robot (**Figure 5**). Experiments have demonstrated that a single robot can perform two major tasks and is mobile, making it innovative and convenient to use virtually anywhere. The robot is characterized by the use of multiple power-assist
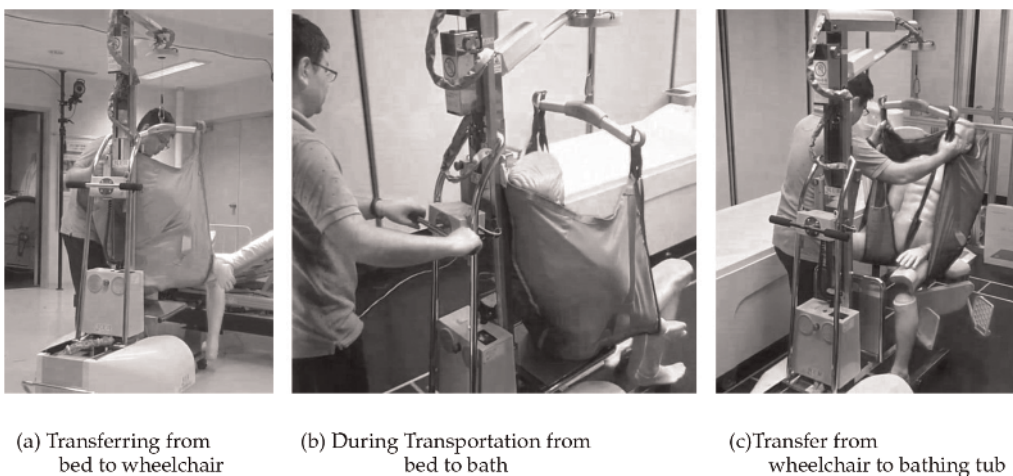

(a) Transferring from bed to wheelchair

(b) During Transportation from bed to bath

(c)Transfer from wheelchair to bathing tub

Figure 4.
The authors have developed a robot that integrates transport and transfer. Power-assisted operation is used for lifting and lowering and moving the robot so that anyone can use it easily.
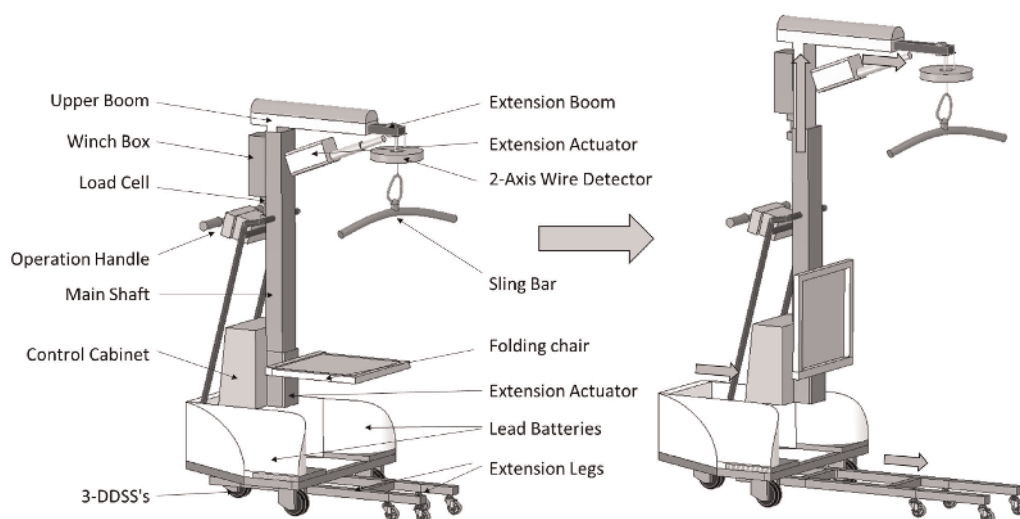

Figure 5.
Image of the deformation mechanism of a robot that integrates transport and transfer. The mechanism expands during transfer operations and contracts when the robot is not being moved or used.

technologies for the desired task. For example, for patient lifting operations, power-assisted movements are realized using multiple sensors built into the wires of the lift. One technology employed is power assist using a tension-type load cell built into the wire traction section. The load on the wire is detected by the load cell, and the speed of the traction motor is controlled based on the displacement to perform lifting. In particular, the controller has been designed to suppress the limit cycle that occurs during descent work when the machine is grounded, thereby achieving smooth control. Another technology employed is an optical sensor that detects the tilt angle of the lift's wires without contact and moves the main body of the robot based on displacement. This can be done seamlessly with the patient lifting operation, allowing the caregiver to move the robot body in any direction and at any speed while supporting the patient with both hands. This allows the caregiver to use both hands to support the patient, which gives the patient a sense of security, unlike pendant-type switches, and because both hands are used for support, there is less swaying and thus safety is enhanced. Furthermore, by employing the aforementioned DDSS in the robot's movement mechanism and mounting a control handle with a force sensor on the backrest, the robot body can move in all directions by power-assist control, enabling operation in the direction of travel and speed as intended by the caregiver. It is not as complicated to control as automatic driving and extremely easy to operate. The results of this integrated care robot research were discussed with medical professionals of Toyohashi Narita Hospital. They commented on the convenience of using a single device to perform two processes. In addition, noting that the power-assist system reduces the workload, they expressed a strong desire to use it. One medical professional commented that he would like to use the robot in the transfer and transportation of patients from the bed to the bathing area.

2.4 Walking training robot combining Niltwamor and Lucia

As a consequence of population aging, the number of elderly people with gait disorders is increasing. Early rehabilitation is important to prevent the elderly from becoming bedridden and to restore their walking ability. The authors have developed two walking robots, Niltwamor (Novel Intelligent Walking Mobile Robot) [19–22] and Lucia [22, 23] (**Figure 6**). Niltwamor consists of an omnidirectional drive system using an omniwheel and a laser sensor, and an unloaded weight support system that suspends the harness independently by two wires. Rehabilitation is considered to be effective when started early after treatment and is particularly suitable in the acute phase when the body is difficult to support. In order to increase the degree of freedom in the direction of gait training, a control system is designed to determine the direction in which the gait training robot moves and the distance it travels by monitoring the direction and step width with a laser sensor when the trainee takes a step. A feature of this system is that the trainee has a high degree of freedom to move in the direction in which he or she wants to go, rather than being restricted to a fixed location as in the case of a conventional treadmill. Since excessive floor reaction force causes recurrence of disability and delay in recovery, and excessive weight bearing decreases the effectiveness of rehabilitation, we proposed an adaptive control system that uses sensors to estimate floor reaction force and control the lifting force to keep the floor reaction force appropriately constant or arbitrary. To evaluate the effectiveness of the proposed gait training robot, Niltwamor was applied to elderly patients undergoing gait rehabilitation. The results showed that the robot operated almost exactly as the patient intended. The physiotherapist commented that the data

Figure 6.
Two robots developed by the authors cooperate in a gait training task, with Lucia (left) providing gait guidance and Niltwamor (right) performing real-time unloaded weight support system that suspends the harness independently by two wires.

obtained online from the sensor, which measures the unloading force and floor reaction force, enables statistical and theoretical analysis of the relationship with the treatment effect, which was previously done empirically, and is effective for use as digital therapy. Lucia, on the other hand, is considered particularly effective for rehabilitation during the recovery period. The robot's approach to measuring and intervening in whole-body movements is promising for motor function rehabilitation. The Robotics Center at TUT has focused on the importance of supporting motor recognition during the recovery process of motor function and has designed a robot system that enhances motor recognition through interaction between a human and a robot. We constructed a system that measures the gait pattern of a trainee using laser sensors and cameras, evaluates the gait condition using digital data and a skeleton model, and determines the gait condition such as a slip gait, a half-turn gait, and a small step gait. The ideal steps of gait are projected on the floor from Lucia by a laser point using image projection control to navigate the gait training. When the gait deviates from the ideal, the vibrator attached to the waist can be controlled to vibrate and stimulate the senses, such as voice, to encourage the user to walk. Experiments involving patients with Parkinson's disease and cerebral palsy verified the effectiveness of the proposed method by examining the advantages of digital motion measurement and sensory stimulation. In the acute phase, Niltwamor can be used by itself; in the next phase, Lucia can be used together with Niltwamor as a navigational system, as shown in **Figure 6**; and finally, in the recovery phase, Lucia alone can be used for gait training, for example, and these two paired robots can be used to train gait step by step. The system can be used for a wide range of applications.

2.5 Power-assisted bed

When moving a bed from a room to a corridor, it is difficult for a single nurse to move the bed due to the weight and maneuverability of the bed, and turning a bed with ordinary wheels in a small room is a challenging task. A bed-cum-wheelchair

called "resyone" has recently been developed, which is unique in that a part of the bed can be removed as a wheelchair for transfer, but the task of detaching the wheelchair from the bed takes a significant amount of time. The author's group has developed a system in which a handle with a force sensor is attached to the rear of the bed, and the direction of the pushing force is used to determine the direction in which the user wants to go, and the speed of bed transportation is determined by the magnitude of the force, taking into account the habits of human operators and automatically controlled by AI (**Figure 7**) [24–26]. Omnidirectional wheels allow the machine to move instantly in any direction. This enables a single nurse to transport a patient in the desired direction and at the desired speed without requiring a great deal of force or turning movements.

2.6 The concept of "weak robots" and social robots in a human-robot symbiotic society

Good coordination between humans and robots is necessary for a society where humans and robots coexist, not to mention in nursing care facilities. Professor Michio Okada of Toyohashi University of Technology has proposed the concept of "weak robots" and has developed a theory and applied it in various fields. He believes that if a robot is too close to perfection and too strong, people are less likely to approach it and that a robot with imperfect elements is often more suitable for daily life [27–29]. For example, unlike Roomba, the Trash Can Robot does not do all the work itself. Children who see it tend to become friendly toward it and actively try to help the robot by picking up trash. Such a response is an important aspect of a rich human life. Extending this idea, we have developed a communication robot Moo and other robots with the aim of stimulating communication and collaboration between caregivers and

Figure 7.
Power-assisted nursing care bed developed by the Authors can be moved in Omnidirectional. The traveling cart, which is add-on to a commercially available care bed, can be easily moved back and forth, left and right, and swiveled by a single person by lightly applying force to the operating handle.

those who need care. Expanding on these studies, we are currently designing and developing various interfaces for social robots (**Figure 8**).

2.7 Care systems and care stations that have been developed

2.7.1 Care scheduling system that coordinates caregivers and care robots

As an example of a care system, we introduce our approach to care scheduling (**Figure 9**) [30, 31]. For people requiring nursing care to use nursing care facilities safely and comfortably, it is important to be able to provide the services desired by the users (persons requiring nursing care) on a just-in-time basis. On the other hand, as the population of people requiring nursing care increases, the burden on caregivers is increasing year by year. Caregiving is hard work, both physically and mentally, and there is an urgent need to reduce this burden as much as possible. In other words, there is a need to create a care plan that improves patient satisfaction and reduces the burden on caregivers. The authors' group has therefore applied combinatorial auction theory to construct a care planning support system that automatically creates a schedule, takes into account the user's preferences for services and caregivers, and determines the assignment of caregivers, including collaboration with robots that reduces the caregivers' burden. Care planning is an urgent issue for nursing homes and hospitals, and this care planning support system needs to be verified in the field in the future.

2.7.2 Nursing care station

To create a showcase for care stations, it is important to develop fundamental technology covering simulation software and animation, scheduling and optimization,

Figure 8.
Weak robots—research on social implementation of relational robots. A weak robot does not hide its weaknesses and imperfections. Rather, by disclosing its weaknesses in moderation, the robot successfully draws out the "strengths and kindness" of those around it.
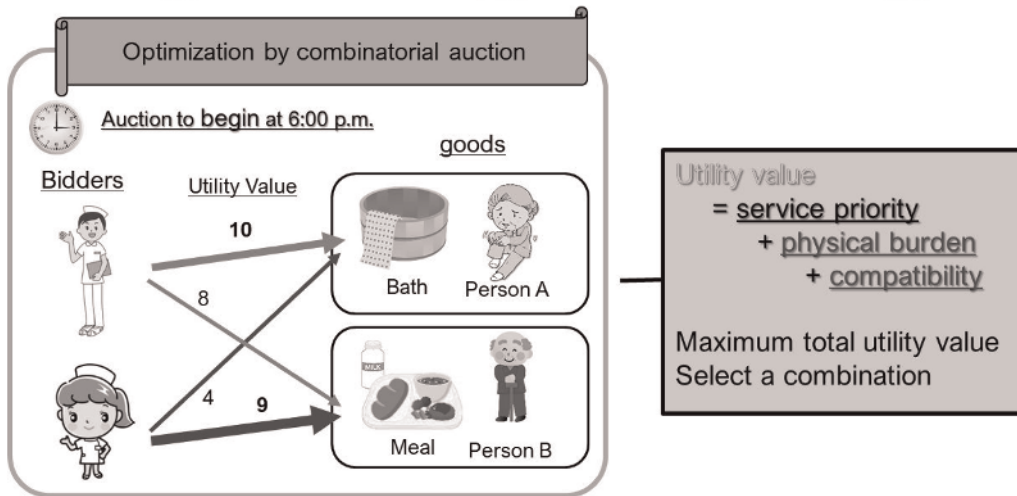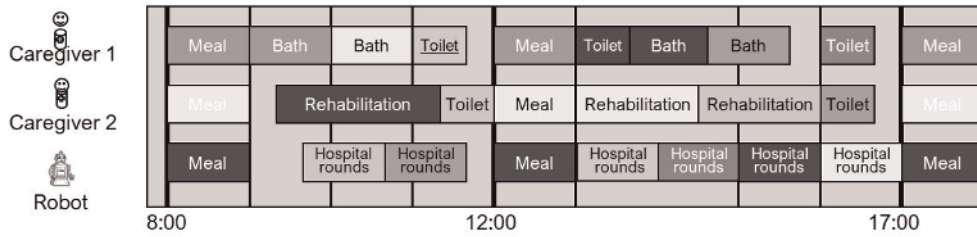
Gantt chart image

Figure 9.
Care scheduling using combinatorial auctions developed by the Authors. Optimization of resources both improves user satisfaction and reduces the burden on providers.

Figure 10.
The authors' prototype nursing station showroom. By placing the various robots developed in the showcase, it is possible to verify not only from the perspective of researchers but also from the perspective of users what kind of robot fits in the nursing-care field.

control software for coordinated work of care robots, monitoring and surveillance, and evaluation and redesign. A showcase for care stations is essential for visualizing the concept and presenting the results. This will provide a venue where medical professionals, researchers, engineers, manufacturers, and those involved in sales and marketing can gather at any time and make it easier for them to create usable products. In terms of providing a venue, the development of a showcase for nursing care robots would also be useful. **Figure 10** is a photograph of a showcase that is part of a care station [32, 33]. Our project pursued development of major care robots as a comprehensive system and involved coordination of robots, care scheduling considering the use of robots, assistive robots considering the roles of humans and robots in a human-robot symbiotic society rather than full automation, social media robots, etc. The main elements of our project were included in the presentation of the 2018 Ministry of Education, Culture, Sports, Science and Technology project's final results. We have achieved a certain level of success and will continue development with a view to realization of smart hospitals.

3. Smart hospital initiative

3.1 What is a smart hospital?

A smart hospital [34] is a new type of hospital that combines information technology and medical technology to ensure the quality of medical care in the coming super-aged society, curb the increase in medical costs, improve international competitiveness in the medical field, and reduce the burden on medical personnel. Also called an AI Hospital [35], it is a facility that will serve as a base for medical care aimed at Society 5.0. Progress toward Society 5.0 in the medical field is divided into four categories: Comfortable living, Health promotion, Optimal treatment, and Reduction of burden (**Figure 11**). Medical big data will be created with digitized medical information and patient health information obtained through IoT devices. The aim of this project is to utilize AI technology to improve health management for everyone and treatment outcomes for patients, provide diagnostic assistance to reduce the burden of medical treatment, and support medical education and communication with patients.

Source: Cabinet office: Examples of Creating New Value in the Fields of Healthcare and Caregiving (Society 5.0). https://www8.cao.go.jp/cstp/english/society5_0/medical_e.html

3.2 What the smart hospital aims to achieve

The advantage of smartization is that it enables optimization for individual patients through the use of data. Capitalism up to now has aimed at the happiness of the greatest number of people by raising the average level, but by responding to individual needs through the use of smart technology, it has become possible to achieve the greatest happiness in terms of diversity of outcomes as well as for the greatest number of people. Smart hospitals aim to achieve the four above-mentioned goals, which are readily divisible into two categories. The first concerns the provision of what not only patients visiting the hospital but also everyone in the community wants from the hospital (**Table 1**), and the second concerns reduction of unnecessary work and tasks so that doctors and nurses can better perform their duties (**Table 2**). What everyone wants from hospitals is an integrated experience that makes them feel
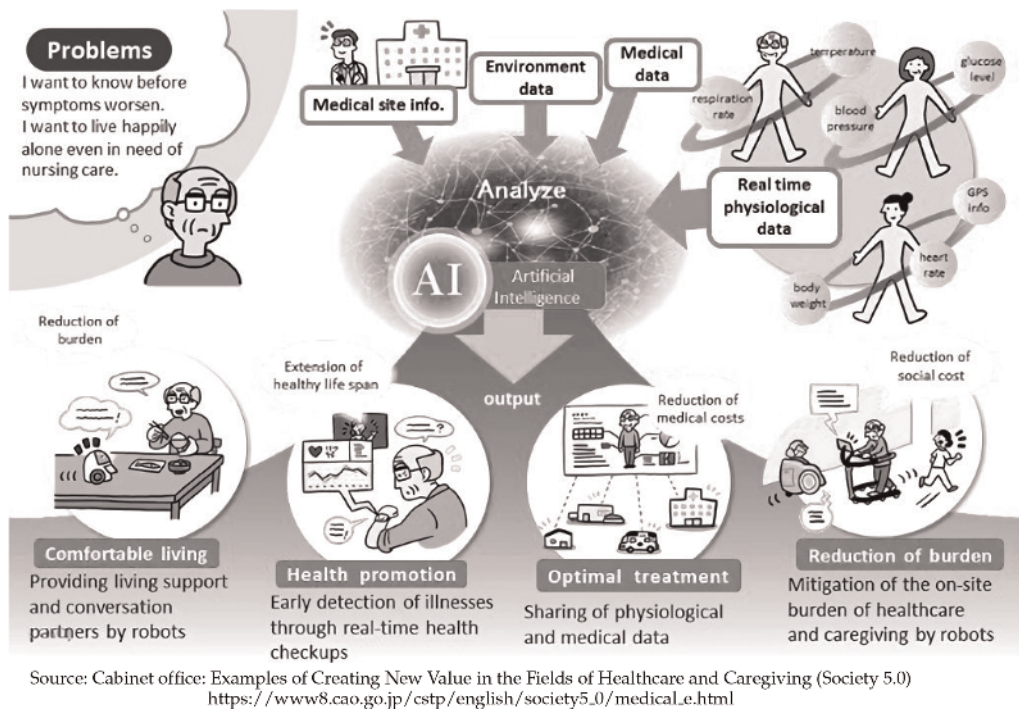
Source: Cabinet office: Examples of Creating New Value in the Fields of Healthcare and Caregiving (Society 5.0)
https://www.8.cao.go.jp/cstp/english/society5_0/medical_e.html

Figure 11.
Society 5.0 in the medical field. AI analysis can provide appropriate resources for various requirements such as life support, health promotion, optimal treatment, and burden reduction.

Provide what people need
• Online reception and automated accounting, but convenience alone is not enough
• Provide an integrated experience that makes people want to visit the hospital and be glad they did
• Responsibility as a health information center to manage the health of the community
• Health management from the viewpoint of pre-symptomatic disease through the Internet of Medical Things (IoMT).
• Explanation of treatment details using augmented reality (AR) etc.

Table 1.
What the smart hospital aims to achieve #1.

What helps doctors and nurses perform their duties better
• Online reception, order management service, medical appointment management application
• Speech input, natural language, and AI-based diagnostic assistance
• Patient risk behavior management by IoMT
• Robots to assist in treatment (surgery, catheterization, etc.), patient care and material handling
• Creation of medical education tools using augmented reality (AR) etc.

Table 2.
What the smart hospital aims to achieve #2.

good about visiting a hospital, as well as the ability to manage community health from the early stages of disease, enabling early detection and treatment of illnesses and early reintegration into society. The smooth transmission of various information, such as health management and early detection of disease using a wearable device with electrocardiogram and other functions, medication management using a smartphone application, alert functions such as the date of a return visit and the order of calls, online reception and automatic accounting, etc., will provide convenience for patients and everyone else. All these elements will contribute to the enhancement of the system. In addition, AI interviewing and diagnostic assistance in the field of medical care will not only shorten the time required for medical treatment but also contribute to an accurate diagnosis. Dictation and natural language software can reduce the time spent on manual entry of medical records, allowing doctors and nurses to spend more time face-to-face with patients, which is the essence of medical care; patient behavior monitoring using IoT devices can help manage risky patient behaviors such as accidental falls and self-extubation. The use of robots in healthcare can also reduce the burden of various tasks such as guiding patients and carrying items. It is also effective in providing medical care in the midst of infectious diseases such as the current COVID-19 pandemic and in preventing the spread of such diseases. It has also been reported that in the medium term it will contribute to reducing the cost of healthcare [36]. Thus, the combination of information technology and medical technology is expected to improve the quality of medical care in various situations.

4. Discussion

In the U.S., the introduction of electronic health records (EHRs) progressed owing to the promotion of IT in the medical field during the Obama administration. The U.S. is a vast country, and the need for telemedicine is high. Subsequently, hospitals, which serve as hubs for digital health, have become smarter and the momentum is accelerating under the influence of COVID-19. China, Australia, and the United Kingdom are also making progress in digital health, with progress in these countries also led by government. Compared to these countries, Japan's digital healthcare is considered to be more than a decade behind. In a report issued in 2015, the OECD (Organization for Economic Cooperation and Development) ranked Japan last among OECD member countries in health information governance and utilization. The reasons for this are 1. ambiguity as to which government department is responsible for the digitization of healthcare; 2. the Galapagos syndrome affecting medical data handling and EHRs, which are also legacy systems; and 3. the impact of the "2000 problem" related to personal information protection legislation on personal health records (PHRs) [37], which prevents PHR standardization. Until a few years ago, Japan had sufficient technology for digitization, but the legal environment was not conducive to its use. However, the government has begun pursuing initiatives to overcome this impasse: In 2019, the Ministry of Health, Labor, and Welfare established the "Consortium for Accelerating AI Development in the Health and Medical Sector" and began government-led activities. In 2020, the Cabinet Office launched a project for social implementation of "Advanced Diagnosis and Treatment System by AI Hospitals," and as part of the project, the AI Hospital Promotion Center was established within the Japan Medical Association in 2021. And with the establishment of the Digital Agency and revision of the Personal Information Protection Law in 2022, standardization of PHRs and their widespread use are expected. The groundwork is now being laid for
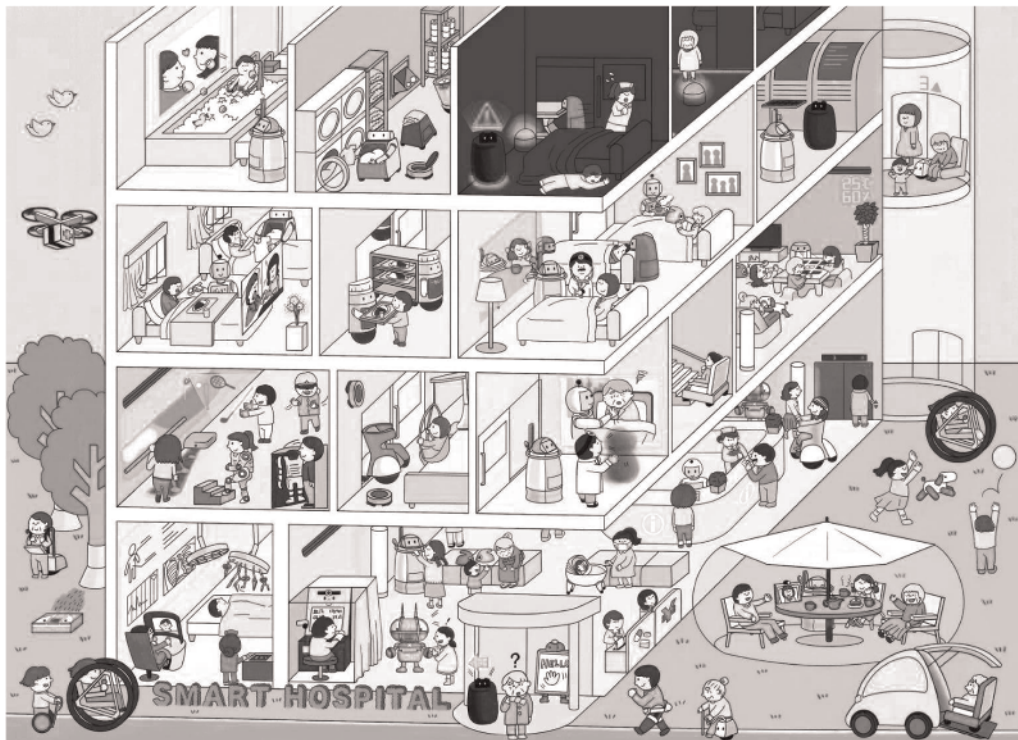
Figure 12.
The Smart Hospital Conceptual Diagram imagined by K. Terashima and M.Takahashi. A hospital of the future where people, IoT, AI, and robots can coexist in optimal symbiosis and perform efficient medical operations that are friendly to patients and healthcare professionals.

the standardization of digital health and smart hospitalization. **Figure 12** is the image of smart hospital concept by Kazuhiko Terashima, Toyohashi University of Technology, and Masami Takahashi, Masami Design Co., Ltd.

5. Future scope

An indispensable element to promote digital health and smart hospitalization is healthcare-industry collaboration. Until a few years ago, the healthcare sector was treated as off-limits, an inviolable sanctuary. However, we believe that the time has come to recognize that this attitude has hindered development of the healthcare sector and that change is overdue. Mutual understanding is essential for smooth healthcare-industry collaboration, and this requires the recruitment and training of human resources capable of working across the boundaries of medicine and engineering. Currently, we consider it necessary to have personnel who can translate needs in the medical sector, including those at the bedside, into the language of engineering and communicate them to those involved in development work and at the benchside [38–40]. In the future, we would like to see healthcare professionals who can do their own programming and engineering professionals who can serve as leaders of medical engineering in the medical field, and we would like to see the emergence of proactive personnel with skills and perspectives who are not content with the status quo. The Toyohashi University of Technology and the Smart Hospital Joint Research Chair were

established, and research has begun on: 1. the application of speech recognition and natural language processing to electronic medical records; 2. image diagnosis support using AI; and 3. the application of behavior recognition technology in the medical field. We would like to provide useful digital health services to patients and the entire community by combining the data we have accumulated in our clinic with the university's advanced technology. Through our activities, we hope to develop a cadre of consummate professionals and invigorate the digital healthcare industry.

6. Conclusion

This paper began by introducing the research on next-generation nursing care systems and stations that have been developed by the authors' group, which are closely related to smart hospitals. Pursuing human-robot symbiosis, the authors' group has developed an assistive robot, which is not fully automated but follows human intention by distinguishing those tasks that are better performed by a human and has also developed a robot that is easy to operate, safe and secure, and comfortable to use. In addition to introducing those robots, the paper introduced care scheduling as part of a total system and referred to a showcase for care stations. Next, the paper presented an overview of smart hospitals and points to keep in mind as the project progresses. We believe it is important to deepen healthcare-industry collaboration and to train people capable of fulfilling important roles in the digital healthcare industry. We hope our work will stimulate future research and development of smart hospitals.

Acknowledgements

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