

Article

Research on Welfare Robots: A Multifunctional Assistive Robot and Human–Machine System

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Abstract: Welfare refers to the state of happiness and well-being experienced by a person. Welfare robots can directly contribute to people's happiness and well-being. Specific welfare robots include health promotion robots, rehabilitation robots, assistive robots, nursing care robots, etc. Welfare robots are used in human living spaces and exert actions on humans through force and information. Because industrial robots that handle objects prioritize high speed and efficiency, if their control methods were to be applied directly to welfare robots, the results would be unsatisfactory and extremely dangerous. This paper proposes a method for constructing a human–machine system for welfare robots that includes the estimation of the user's work intention, a measurement of riding comfort, and motion generation. Furthermore, various types of welfare equipment for people with walking disabilities have been developed, but most of them have a single function. Equipping small homes with many single-function devices is difficult, and their use is complicated and not standardized. Therefore, in this study, we developed a multifunctional assistive robot that integrates mobility, transfer, work support, and training. It is a typical welfare robot and is effective in preventing a user's minor disabilities from becoming more severe. In this paper, we discuss the research challenge points of human–machine welfare robot systems and their current situation using the multifunctional assistive robot as a typical example.

Keywords: welfare robots; multifunctional assistive robot; human–machine system; intention estimation; measurement of riding comfort; motion generation



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1. Introduction

A recent survey by the United Nations revealed a demographic shift owing to a decline in births and an increase in the elderly population [1]. For the first time in history, the elderly population over the age of 65 has surpassed the number of children under the age of 5, and their population is expected to increase by more than double by the middle of the twenty-first century. The world is now rapidly aging and is about to experience a super-aged society, as defined by the United Nations [1,2].

In an aging society worldwide, if social well-being (health, medical care, assistance, nursing care, etc.) is universally improved, older people will be able to live happily with no worries. To improve people's well-being, prolong healthy life expectancy, and achieve a society in which all people are happy, many countries have implemented strategic countermeasures. In the field of robotics, various welfare robots are being developed [3–8]. Welfare refers to the state of happiness and well-being experienced by a person, and welfare robots are robots that can directly contribute to people's happiness and well-being. Welfare robots operate in human spaces, interacting directly with and serving humans. The scope of welfare robots is broad but not abstract. Robots that can contribute specifically to health promotion (disease

prevention), rehabilitation medicine (functional recovery), and life support (functional assistance) can be collectively referred to as welfare robots [3]. As a solution to the problems of an aging society, the field of research into welfare robotics comprises three primary areas: health promotion, rehabilitation medicine, and functional assistance.

First, age is not an essential problem in an aging society. The more experienced and healthier the elderly population is, the more efficient society as a whole will be. All things in nature undergo the process of “birth, growth, maturity, decay, and death”, including human beings. For each individual, if the process of “ripeness → decline” can be prolonged, a high-quality life can be achieved. A long and healthy life is a happy life, which can result in a vibrant society [3]. In order to promote people’s health, a riding robot system was developed using a six-degrees-of-freedom parallel robot that faithfully reproduces the movements of a live horse and uses virtual reality (VR) technology [3,9]. The effects of exercise intervention using the equestrian robotic system were examined, and significant improvements were observed in all measured items for frail elderly and young people [10,11]. Furthermore, a new robotic horseback-riding simulator was proposed, and multiple equine therapies for treating gross motor function in children with cerebral palsy were developed [12–14].

Next, owing to changes in the living environment, eating habits, and various stresses, humans can become ill, similar to machines that break down due to strain. Chemical approaches using medicine are available to cure illnesses, as well as physical approaches such as surgery and rehabilitation. If a person is unable to walk owing to a cerebral infarction or spinal cord injury and is unable to recover, their range of activities will gradually narrow, their mental and physical aging will accelerate, and they will often become bedridden [15,16]. Therefore, in the field of rehabilitation medicine, gait training as a physical function recovery is considered the most important, and various gait training devices have been developed [17–19]. Recently, an omnidirectional gait training robot was researched and developed to improve gait while correcting posture [20].

However, in some cases, walking function cannot be restored even with gait training. Enabling independent living by assisting lost functions is one of the aims of the field of welfare robots [3,4]. Thus, as a physical functional aid for people with walking disabilities, electric wheelchairs have been actively researched and developed, but most of them are only a passive means of transportation [21–25]. People with walking disabilities are also prone to upper body disuse syndrome. Elderly people who are essentially gait-impaired tend to stay in bed and eventually rapidly fall into a bedridden state [26,27]. Recently, various devices have been developed for people with walking disabilities or weak standing posture, such as silver cars for mobility, walking wheels, electric wheelchairs, training walkers, chairs to support standing, and lifts for transfers. However, most of these devices have only a single function. Equipping a small home with many single-function devices is difficult. The use of these devices is not standardized and can be cumbersome. Therefore, in this study, we developed a multifunctional assistive robot that integrates mobility, transfer, work support, and training as an effective and easy-to-use functional assistance robot for preventing mild disabilities from becoming more severe.

Furthermore, the control theory for industrial robot systems that handle objects was largely established in the early 1990s. Target values (position and velocity) are given externally, and high speed and efficiency are pursued. In contrast, welfare robots that aid humans do not require high speed; they provide functional assistance by exerting force on the user. If the control methods of industrial robot systems were directly applied to welfare robots, the results would be unsatisfactory and extremely dangerous. In addition, the target values (position and speed) of the welfare robot system are not given externally; instead, the support motion that satisfies the user’s intention and riding comfort must

be generated internally and automatically. Therefore, this paper proposes a method of constructing a human–machine system for welfare robots that includes an understanding of a user’s intention, a measurement of riding comfort, and motion generation.

In this paper, we first describe the features, prototype, and mathematical model of a multifunctional assistive robot. Next, we propose a method for constructing a human–machine system for welfare robots. We discuss the research challenge points of servo control, intention understanding, riding comfort measurement, and motion generation in the human–machine system, assessing the current situation using a multifunctional assistive robot as a typical example. We also discuss a trial use of the multifunctional assistive robot in a welfare facility and hospital. Finally, we describe the prospects of the human–machine system for welfare robots.

2. Multifunctional Assistive Robot

Currently, various devices and robots are being developed to support the living and rehabilitation of elderly people and people with disabilities. However, due to the single function of these devices, they cannot meet the needs of all the basic movements required for independent living. It is also difficult to equip a small home with a large number of single-function devices. In addition, the use of these devices is not standardized and is complicated. For assistive robots to truly contribute to the popularization of society, robots must be multifunctional. In this study, we developed a multifunctional assistive robot that integrates transferring, moving, training, and work support, which are considered to be the most basic functions in daily life.

2.1. Robot Features

The multifunctional assistive robot is shown in Figure 1. For use in small homes or private rooms in facilities, it uses omnidirectional movement technology with small high-power omni-wheels. The seat is fabricated from soft material. Unlike ordinary wheelchairs, the seat is narrower in the front than in the rear, enabling use in a straddling position. This enables the user to perform various daily activities.

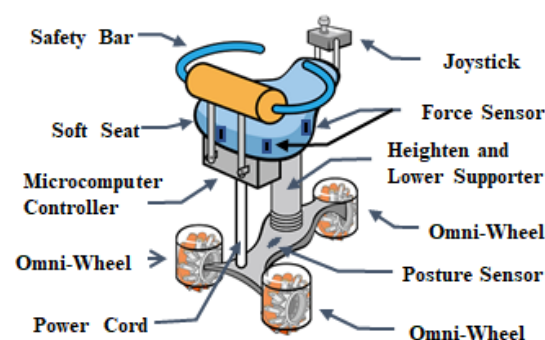


Figure 1. Multifunctional assistive robot.

As shown in Figures 1 and 2, the safety bar enables the left and right armrests to rotate in a 90° range and the foldable backrest to retract 180° to the rear to achieve zero-distance access to a bed, sofa, or toilet bowl during transfers. The height can be adjusted vertically to accommodate users of different heights and to work at different altitudes and heights. A joystick is also provided, but it can be stored in the lower part of the wheelchair, similar to the driving operation of an electric wheelchair. This enables the user to climb on and off the wheelchair from a chosen direction and in a comfortable posture. Electric cords and a microcomputer are placed in a control box or pipe to conceal them.

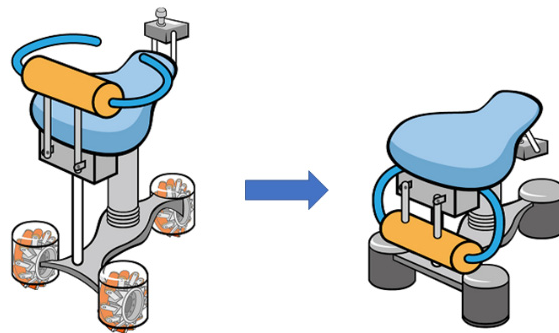


Figure 2. Height adjustment and storage underneath.

With a posture sensor attached to the main body, the system measures the relative relationship between objects and people during autonomous movement in a room and guides the user to their destination while avoiding the objects. Force sensors are installed in four locations to measure the position of the user's center of gravity and the direction from the center toward the center of gravity in real time, enabling operation by turning the body to one side.

It has three operation methods: ① the hand operation mode, ② the foot operation mode, and ③ the body tilt operation mode. Operation mode ① is used for mobility and work assistance; operation mode ③ is used for training and rehabilitation; and operation mode ② is used for transfers. Operation mode ①, which uses a joystick, is the same as operating a normal electric wheelchair, but mode ②, which uses the feet, and mode ③, which uses body tilt, are modern and easy to switch between each other, enabling the user to operate them instantly.

Figure 3 shows example uses of the multifunctional assistive robot that maximizes the use of upper body locomotors to prevent a person with a walking disability from becoming bedridden.

Figure 3a–g show images of various work supports such as cleaning, carrying, and meal preparation; Figure 3h,i show images of moving in a confined space and avoiding obstacles; Figure 3j–l show transfer support; Figure 3m shows stand-up support; and Figure 3n shows seated walking training.

2.2. Robot Prototype

The prototype of the multifunctional assistive robot is shown in Figure 4. Figure 4a,b show the altitude adjustment of the main body, and Figure 4c shows the left and right armrests rotated at 90° and the foldable backrest stowed backward at 180°.



(a) Cleaning.

(b) Transportation.

(c) Wiping a table.

Figure 3. Cont.

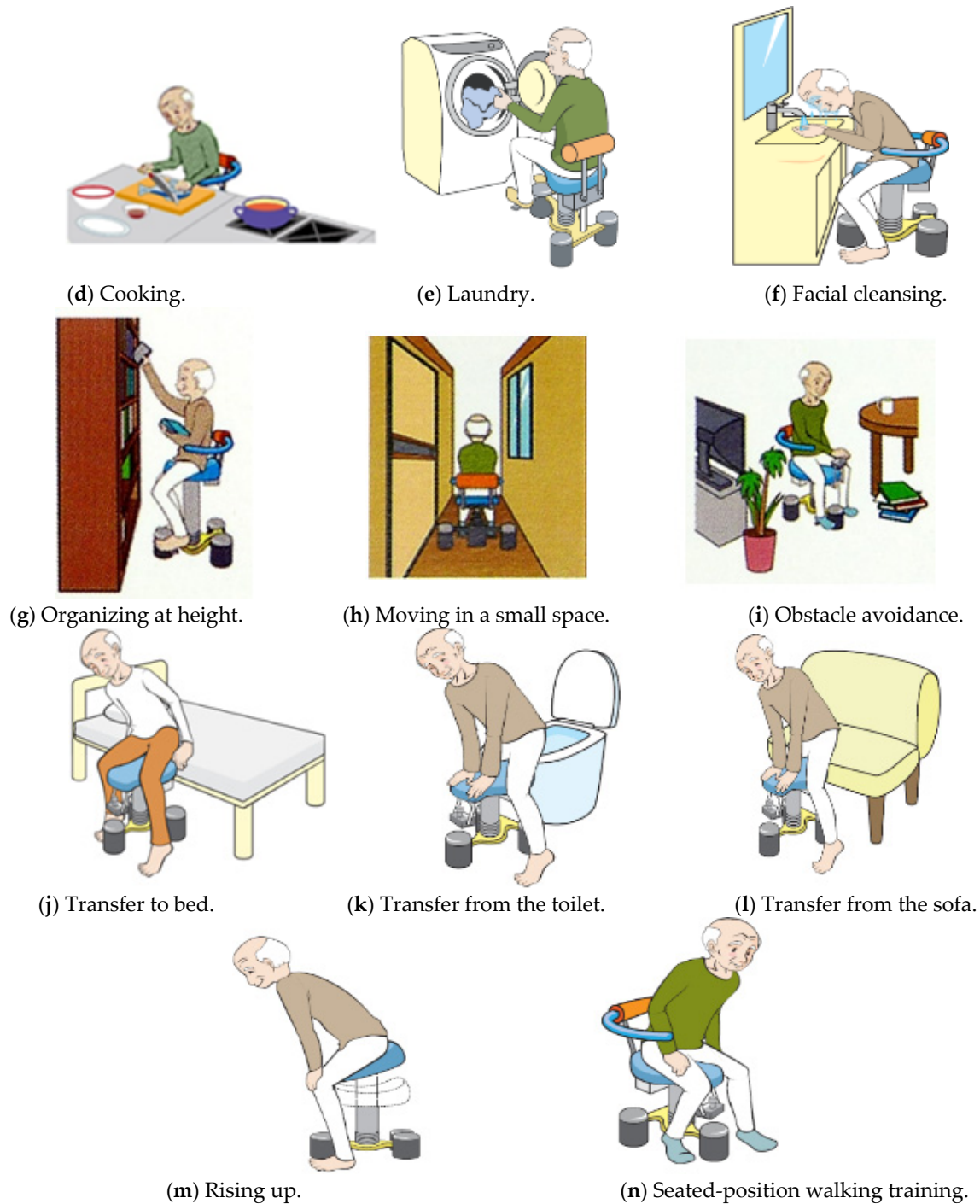


Figure 3. Example uses of the multifunctional assistive robot.

The outer diameter is $W630 \text{ mm} \times D670 \text{ mm} \times H760 \text{ to } 1070 \text{ mm}$, the adjustable seat height range is 400 to 710 mm, and the cart weight is about 40 kg. All three drive wheels use an omni-wheel unit integrating a motor and reduction gear. The power source is a lead–acid battery that operates continuously for 3 to 4 h on a full charge. The maximum passenger weight is 80 kg, and the travel speed is 1.07–2.73 km/h.

2.3. Mathematical Model

To develop the control method, we derived the kinematics and dynamics of the multifunctional assistive robot. The coordinate setup and structural model are shown in Figure 5.

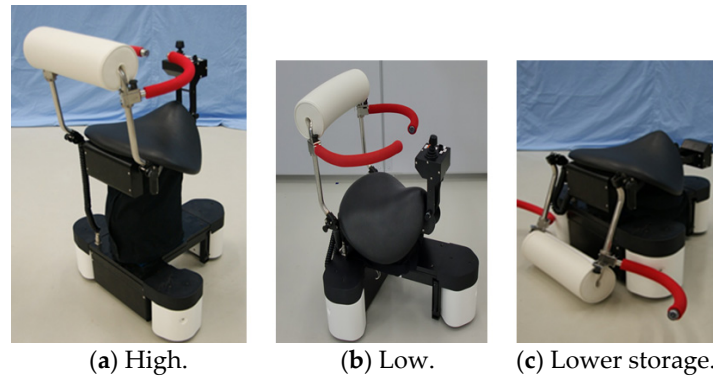


Figure 4. Prototype of the multifunctional assistive robot.

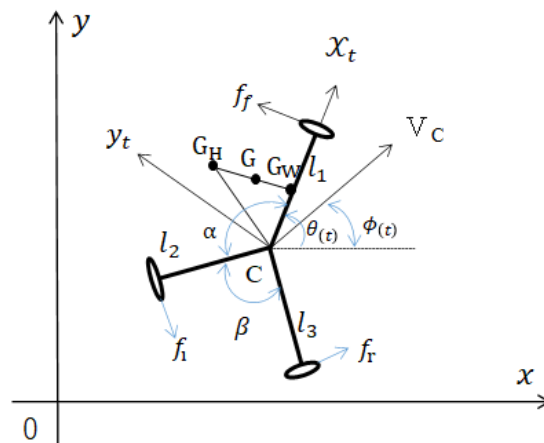


Figure 5. Robot coordinate settings and structural model.

The parameters in Figure 5 are defined as follows:

$\Sigma(x, y, 0)$: Absolute coordinate system.

$\Sigma(x_t, y_t, C)$: Relative coordinate system.

$F = (f_f, f_l, f_r)^T$: Driving force vector.

$V_C = (v_{Cx}, v_{Cy})^T = (\dot{x}_C, \dot{y}_C)^T$: Movement speed vector.

$V = (v_f, v_l, v_r)^T$: Tangential velocity vector of each drive wheel.

l_1, l_2, l_3 : Distance from the driving wheel to the geometric center.

$\theta(t)$: Angle between the x- and y-axes.

$\phi(t)$: Angle between the x-axis and the moving speed.

α : Angle between the front and left (or right) wheel directions.

β : Angle between the left and right wheel directions.

m, M : Mass of the robot; weight of the user.

I : Moment of inertia around the Z-axis passing through the center of gravity, G , of the robot.

d_1 : Distance between the robot's center of gravity and the center.

d_2 : Distance between the user's center of gravity and the center.

d_3 : Distance between the centers of mass of the robot and the user.

For this coordinate system, the kinematics are described in Equation (1) and the dynamics are shown in Equation (2).

$$\begin{bmatrix} -\sin(\theta) & \cos(\theta) & l_1 \\ -\sin(\alpha + \theta) & \cos(\alpha + \theta) & l_2 \\ -\sin(\alpha + \beta + \theta) & \cos(\alpha + \beta + \theta) & l_3 \end{bmatrix} \begin{bmatrix} \dot{x}_C \\ \dot{y}_C \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} v_f \\ v_l \\ v_r \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} m+M & 0 & 0 \\ 0 & m+M & 0 \\ 0 & 0 & (I+d_1^2m+d_2^2M) \end{bmatrix} \begin{bmatrix} \ddot{x}_C \\ \ddot{y}_C \\ \ddot{\theta} \end{bmatrix} + \begin{bmatrix} \sin(\theta) & \sin(\alpha+\theta) & \sin(\alpha+\beta+\theta) \\ -\cos(\theta) & -\cos(\alpha+\theta) & -\cos(\alpha+\beta+\theta) \\ -l_1 & -l_2 & -l_3 \end{bmatrix} \begin{bmatrix} f_f \\ f_l \\ f_r \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix} \quad (2)$$

3. Human–Machine System for Welfare Robots

Welfare refers to the state of happiness and well-being experienced by a person. Welfare robots can directly contribute to people's happiness and well-being [3]. Specific welfare robots include health promotion robots, rehabilitation robots, assistive robots, nursing care robots, etc.

In this chapter, we first explain the differences between industrial robots and welfare robots in terms of system construction; then, we propose a human–machine system construction method for welfare robots. Next, using a multifunctional assistive robot as an example, the characteristics of welfare robot systems and the challenge points of the research are discussed.

3.1. Human–Machine System Construction

As shown in Figure 6, in an industrial robot system, the control object is an inanimate object, and the target values of the system, such as position and speed, are given externally, with the aim of attaining high speed and efficiency.

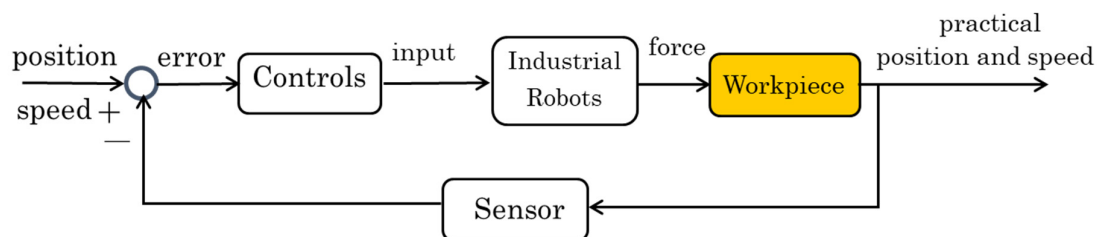


Figure 6. Industrial robot system.

In welfare robot systems that interact with people, their purpose is to robotically assist the user in moving around, assisting in their daily life and activities, and so on. Therefore, welfare robot systems do not need to attain high speed or high operational efficiency. If conventional control methods for industrial robot systems were directly applied to welfare robots, one would attain unsatisfactory control results, and great danger would be posed to a user. Constructing a welfare robot system requires the robot to understand the user's intent (orientation intent, behavioral intent, etc.) and to consider the user's comfort, posture, and center-of-gravity position during the control process; the system's target value is not given by a higher-level system but is automatically generated within the system under the premise of satisfying the user's intent and comfort. In this paper, as shown in Figure 7, for the welfare robot, we propose a human–robot system construction method that includes an understanding of the user's intention, the measurement of ride comfort, and motion generation. In other words, we construct a total system that considers the user's intentions and riding comfort, generates safe actions based on those data, and safely controls the robot (Figure 7).

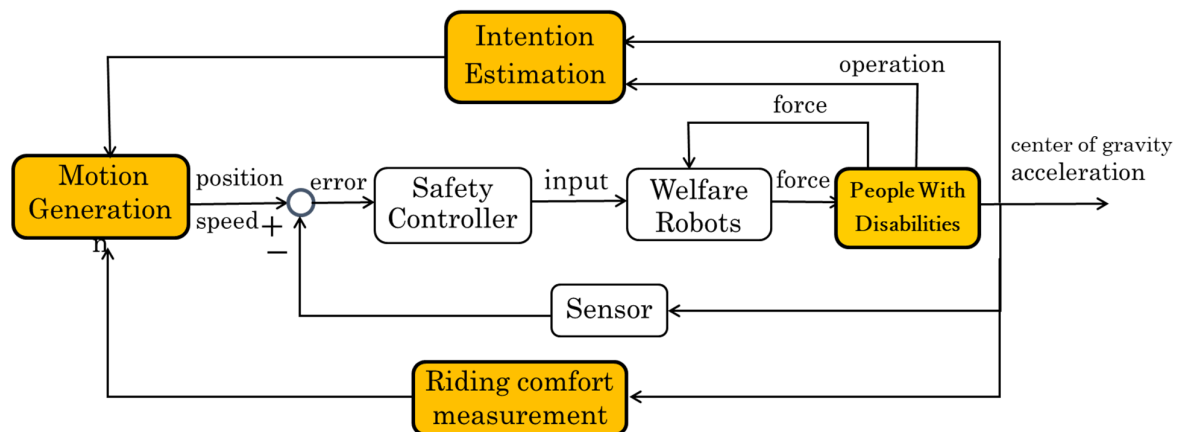


Figure 7. Human-machine system for welfare robots.

In the following sections, we discuss the research challenge points that arise in addressing welfare robot human-machine systems and the current situation, as shown in Figure 7, using the multifunctional assistive robot shown in Figures 1 and 3 as an example.

3.2. Servo Control

As shown in Figure 3, the multifunctional assistive robot assists the user not only in moving but also in transferring, standing, daily tasks, and seated-position walking training. Therefore, advanced servo control methods are required.

3.2.1. Handling Center-of-Gravity Misalignment

In daily work and seated walking training, the center of gravity of the robot shifts from its geometric center, owing to the influence of the user's upper body movements (e.g., changes in the sitting position and posture). If the driving force acting on the robot is left unchanged, the robot generates extra rotational motion in its linear motion, owing to center-of-gravity misalignment. This not only affects the accuracy of the robot's trajectory tracking but may also cause the robot to fall over.

The problem of center-of-gravity misalignment is an important issue for welfare robots. However, the extent of the center-of-gravity misalignment varies greatly depending on the actual use case (work content). For example, when a user is working in front of a table, as shown in Figure 3c,d, or moving, as shown in Figure 3h,i, there is only a small center-of-gravity misalignment. If the center-of-gravity misalignment is within a negligibly small range, the most practical and effective PID control method is sufficient. However, there are sweeping tasks, as shown in Figure 3a, transfers, as shown in Figure 3j–l, and standing and seated walking training, as shown in Figure 3m,n; these have a large range of center-of-gravity offsets. For the problem posed by wide ranges of center-of-gravity shifting, the adaptive-control method of identifying the center-of-gravity position, although effective, is not practical if the center of gravity is not homogenized quickly. In response to this, several advanced control methods have been proposed [28–31]. However, these methods have not been experimentally verified.

3.2.2. Handling Nonlinear Frictional Forces

To enable use in a narrow environment, the multifunctional assistive robot uses a small Mecanum wheel with a built-in motor and sensor. Unlike conventional wheels, the frictional force on the Mecanum wheel from the floor is nonlinear and depends on the angle between the body and the direction of movement, which is a challenge for servo control. Furthermore, the frictional force differs significantly between different flooring materials, such as wood-based, fiber-based, and resin-based flooring. In order to fundamentally solve

this nonlinear friction problem, a digital acceleration control method based on the physical motion process of the mechanical system was developed [32]. However, since the inertia matrix of the digital acceleration control method is known, it is not yet applicable to the various cases shown in Figure 3 without improvement. A feedforward friction observer was also proposed [33]. Regarding the nonlinear friction problem, there is great potential for developing simple and effective control methods to deal with nonlinear friction—this would be useful not only for welfare robots but also in the field of robotics as a whole.

3.2.3. Safety Control

Unlike industrial robots, the welfare robots do not control objects but humans. Welfare robots are used in human living spaces and exert actions on humans through force and information. Therefore, safety must be ensured.

A common safety measure for robots is the installation of hardware such as emergency stop buttons, safety circuits, and speed-limiting mechanisms. However, a more important aspect is to achieve safety and security from the perspective of control. We only need to examine the process of a human driving a car to easily understand its importance. The driver is equivalent to the controller, and the driving method in the brain is equivalent to the control algorithm. Most traffic accidents are not caused by the fault of the car itself but by the wrong driving method being employed by the driver. Therefore, controller design that ensures safety is essential for welfare robot systems. Research on controller design for safety has been conducted in the development of omnidirectional walking training robots [34]. It can be extended to multifunctional assistive robots. Regarding safety control, model-free safety-critical control, safety-based speed control using robust adaptive model predictive control, and fast computational path tracking control strategies considering safety and stability are also proposed [35–37].

3.3. Intention Estimation

The user's intentions (e.g., direction of movement, transfer, various tasks, standing, sitting, and gait training) can be transmitted to the robot by operating joysticks or other devices. However, as shown in Figure 3, when no hand is available to operate a joystick or another device when carrying an object with both hands (Figure 3b) or cleaning (Figure 3a), the assistive robot must estimate the user's motion intention to provide appropriate assistance.

Human intentions, especially those expressed as fuzzy concepts, are difficult to infer using binary logic reasoning methods [38–40]. Based on a distance-type fuzzy inference method, we developed an approach for inferring the user's intention (direction of movement, transfer, various tasks, standing, etc.) from upper body motions via wearable sensors [41]. However, for more complex intent inferences, an inference method that type-2 fuzzy inference or extends fuzzy sets to graphs would be more effective [42–45].

3.4. Measurement of Ride Comfort

As shown in the human-machine system of the assistive robot in Figure 7, a human who has difficulty walking is transported during the movement and work support operation. This is fundamentally different from the industrial robot shown in Figure 6, and the comfort of the person being moved must be considered. Ride comfort can be assessed essentially by the acceleration to which the human body is subjected. There are various methods of measurement. We have developed a simple method: a force sensor is embedded in the soft seat, allowing the acceleration of the user's center of gravity to be calculated in an approximate manner. If the acceleration of the center of gravity produced by the motion is moderate, good ride comfort can be achieved. However, based on the experimental results, further improvement in accuracy is needed.

3.5. Motion Generation

Because the welfare robot operates in the same space as humans, it must generate motion that provides security to humans while ensuring safety. In other words, it must generate paths and trajectories for comfortable assistance. Although many path and trajectory planning methods have been proposed for industrial robots to achieve high speeds, these are not applicable to welfare robots that assist humans. Welfare robots must generate safe actions based on a user's work intention in a safe domain; ride comfort information can be obtained from ride comfort measurements. If robots are controlled by reassuring motions, robots can assist people in their lives in a safe and reassuring way. This is a challenging topic that has not yet been fully researched.

4. Robot Trial and Discussion

In order to confirm the practicality of the developed multifunctional assistive robot, trials were conducted in a nursing home (12 patients) and in a rehabilitation patient ward (2 patients) and interviews were conducted. In addition, the feasibility of seated gait training was verified in a university laboratory (3 patients). These trials and experiments were reviewed by the Ethical Review Committee of Kochi University of Technology prior to their commencement. The license number was 31-132.

4.1. Trial Use

Figure 8 shows some of the uses of this robot in a nursing home. Figure 8a shows someone explaining the use of the robot. Figure 8b shows the rising-up operation. Figure 8c shows the robot moving laterally in front of a table. Figure 8d shows the transfer from a bed. Figure 8e shows the transfer to a bed. Figure 8f shows the transfer from a sofa. Without any special training or practice, the trial went smoothly. It is recognized that welfare facilities require assistive robots with a variety of functions.

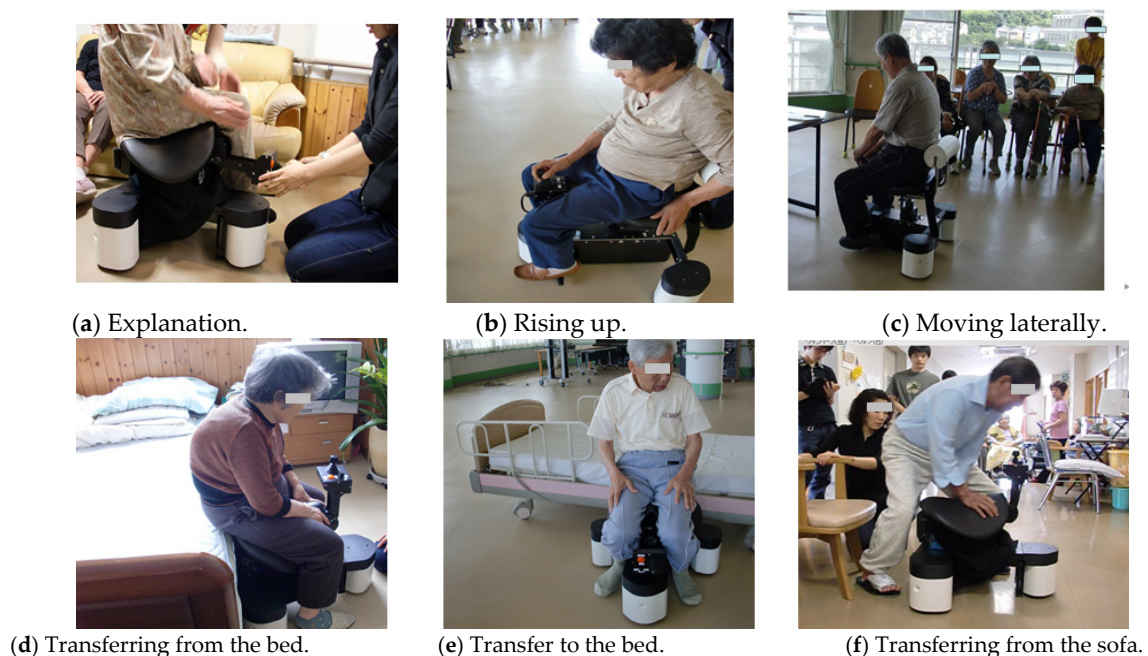


Figure 8. Trial of the multifunctional assistive robot in a welfare facility.

Rehabilitation patients tried the robot in their wards and toilets. The trials are shown in Figures 9 and 10. Figure 9a shows the patient sitting up from the bed. Figure 9b,c show the transfer from the bed. Figure 9d,e show movement within a small hospital room. Figure 11f shows the movement in the hallway. Figure 10a,b show the transfer from a toilet

bowl, and Figure 10c shows the robot leaving the toilet. The above trials were performed smoothly without any special training or practice.

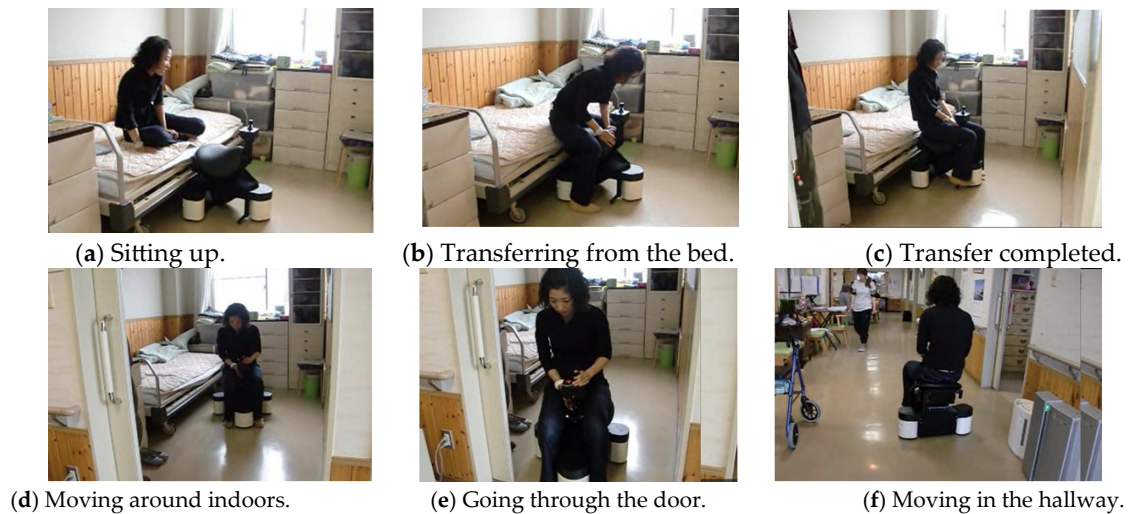


Figure 9. Trial in a rehabilitation patient's room.



Figure 10. Trial use of the multifunctional assistive robot in a restroom.

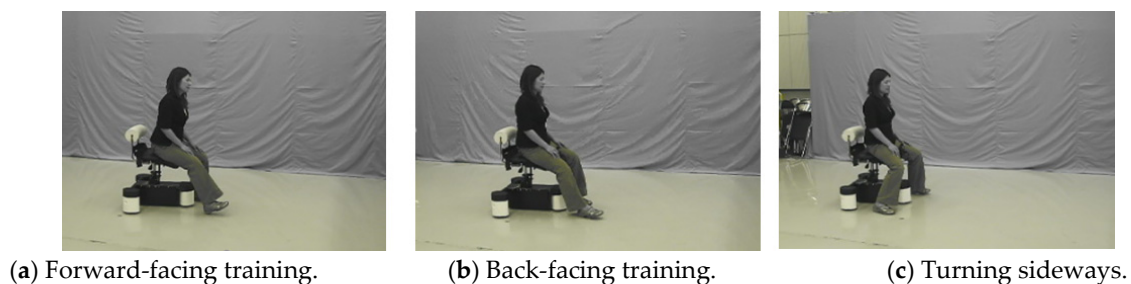


Figure 11. Seated-position walking training.

We also conducted a seated walking training experiment in the university laboratory. The experimental situation is shown in Figure 11. Figure 11a shows the experimenter facing forward, Figure 11b shows the experimenter facing backward, and Figure 11c shows training with the experimenter facing sideways. It is demonstrated that this robot can not only assist in a user's daily life but also perform a full range of walking training activities.

4.2. Discussion

Elderly people and people with disabilities who have difficulty walking or are unable to walk at all are more likely to develop upper body disuse syndrome. There is a concern that older adults who are otherwise only walking-impaired may become "bedridden older adults" and rapidly end up in a bedridden state. Therefore, it is important for people with walking disabilities to actively use their healthy upper body in order to retain as much residual upper body function as possible. The purpose of this study is to promote

upper body health and improve the self-care ability of people with walking disabilities by assisting their physical function. Recently, various types of welfare equipment for people with walking disabilities have been developed, but most of them have a single function. Equipping small homes with many single-function devices is difficult, and their use is complicated and is not standardized. In this study, we developed a multifunctional assistive robot that integrates mobility, transfer, work support, and training. It is a typical welfare robot.

Through the trial use of the multifunctional assistive robot in nursing homes, rehabilitation wards, and laboratories, the characteristics of the robot were verified, and the importance of human-machine system construction for the application of welfare robots in real society was recognized.

The following findings were confirmed regarding the robot's characteristics.

1. The robot uses omnidirectional movement technology (compact, low-speed, and high-power omni-wheels). Thus, it can move smoothly even in small facilities or private rooms in hospitals. When moving in front of a workbench in a small room, it can easily achieve direct lateral movement rather than rotational advancement.
2. The height of the robot can be adjusted. Thus, it can accommodate users of different heights and adjust to the height of the objects being transferred. Furthermore, it can enable a user to reach objects in high places or on the ground.
3. The seat shape of the robot is narrower at the front than at the back, unlike a normal wheelchair. Thus, the user can sit on the robot in a straddling position, which provides a sense of security and enables the user to flexibly perform various movements.
4. The robot can achieve zero distance between itself and a bed or toilet when transferring.
5. A user can climb on and off easily in a comfortable position.
6. With an orientation sensor attached to the main unit, it can measure the relative relationships between objects and people while moving autonomously within a room and move to its destination while avoiding these obstacles.

In addition, industrial robots that handle objects are designed for high speed and high efficiency; if their control methods were directly applied to welfare robots, the results would be both unsatisfactory and very dangerous. This paper proposes a method for constructing a human-machine system for welfare robots that includes an estimation of the user's work intention, measurement of riding comfort, and motion generation.

The multifunctional assistive robot is a typical example of a welfare robot. Through trials of the multifunctional assistive robot in a welfare facility and rehabilitation ward, we observed that a standalone, multifunctional, and independent assistive robot that achieves various support movements should accurately understand the user's intention, actively generate motion, and control it in a manner that is both comfortable and safe for the user.

5. Conclusions and Future Research Directions

Over 7 million years of evolution, humans have coexisted with nature, pursued "life" and "joy", created tools and language, and achieved a high level of civilization. It took humans only 100 years to extend their average lifespan by 50 years. In response to a suddenly aging society, many countries worldwide have implemented corresponding strategic countermeasures. Correspondingly, in the field of robots, diverse welfare robots have been developed for health promotion, rehabilitation medicine, life assistance, disability care, etc.

Various devices have been developed for people with walking disabilities and weak standing postures, but most of them have only a single function. Equipping a small home with many single-function devices is difficult, and their use is complicated and is not standardized. In this study, we developed a multifunctional assistive robot that integrates

transfer, mobility, training, and work support. It is a typical welfare robot. Furthermore, industrial robots handle objects and prioritize high precision and speed; if those control methods were to be applied directly to welfare robots, they would not yield satisfactory results and would be extremely dangerous. Therefore, this paper proposes a human–machine system construction method for welfare robots that includes the incorporation of intention estimation, riding comfort measurement, and motion generation. Using a multifunctional assistive robot as an example of a welfare robot, the characteristics of welfare robot systems and the challenge points of the research are discussed. We also discuss the trial use of the standalone multifunctional assistive robot in welfare facilities and hospitals.

This paper has clarified the concept of the welfare robot system and the necessary functions and interrelationships of welfare robots from the perspective of control engineering. Therefore, we believe it can provide a paradigm for next-generation welfare robots and inspire a new trend in research and development. The widespread use of this welfare robot in society can reduce the workload of medical professionals and caregivers looking after people with disabilities, expand the sociality of people with disabilities, improve their quality of life, and reduce the number of people who are bedridden, thereby contributing to the creation of a vibrant society.

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Institutional Review Board Statement: The safety of the assistive robot was reviewed and approved by the ethics committee of Kochi University of Technology prior to the experiment. The approval number was 31-132.

Informed Consent Statement: Informed consent was obtained from all subjects involved in this study.

Data Availability Statement: The datasets generated during this study are available from the corresponding author upon reasonable request. The data are not publicly available due to privacy.

Conflicts of Interest: The author declares no conflicts of interest.

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