SIN-CHN
SCIENTIFIC PRESS PTE.LTD.

Molecular & Cellular Biomechanics 2025, 22(3), 907.
https://doi.org/10.62617/mcb907

Article

Research on biomechanics-based design of home-based intelligent elderly care robot

Yaqi Gao[1,*], Xiaopeng Pei[2], Minghui Cheng[3]

[1] School of Nursing, Hebi Polytechnic, Hebi 458030, China
[2] School of Education and Arts, Hebi Polytechnic, Hebi 458030, China
[3] School of Data Science, Hebi Polytechnic, Hebi 458030, China
*** Corresponding author:** Yaqi Gao, 15503929190@163.com

CITATION

Gao Y, Pei X, Cheng M. Research on biomechanics-based design of home-based intelligent elderly care robot. Molecular & Cellular Biomechanics. 2025; 22(3): 907. https://doi.org/10.62617/mcb907

ARTICLE INFO

Received: 25 November 2024
Accepted: 11 December 2024
Available online: 18 February 2025

Abstract: Based on the theoretical knowledge of biomechanics, this paper parameterizes the biological structure of the human body and constructs a human biomechanical model in three dimensions: horizontal dimension, vertical dimension, and torsion dimension, and analyzes in detail the relationship between the stresses in the process of intelligent assistance for nursing robots. Based on the human biomechanical model, the overall design scheme of the home-based intelligent elderly care robot is determined, and corresponding software and hardware are used to realize the design of the home-based intelligent elderly care robot. Select experimental tools and test environments to verify and analyze the biomechanics-based elderly care robot. The error between the theoretical value (software simulation results) and the actual value (equipment test results) of the force of the intelligent assistive process of the nursing robot is kept below 5%. The correct rate of urinary and fecal flushing detection of the home smart elderly care robot is more than 0.95, and the response speed of the control system is controlled within 5 s, while the Central Processing Unit (CPU) occupancy rate is not more than 30.00%, which indicates that the home smart elderly care robot can be effectively used in the elderly care work. The combination of biometrics and information technology is a prominent contribution of this article.

Keywords: biomechanics; nursing robot; intelligent aging; control system

1. Introduction

In recent years, with the rapid development of the Internet, big data, and Internet of Things (IoT) technologies, more and more researchers have introduced smart home technologies into home care scenarios in order to solve the problem of aging at home [1,2]. In the aging-in-place scenario, smart home technologies have three main functions, firstly, monitoring the quality of the living environment of the elderly, secondly, monitoring the activities of daily living (ADL) of the elderly, including fall detection, and lastly, long-term health monitoring of the elderly, which includes early diagnosis and intervention of geriatric diseases [3–5]. However, due to the gradual degradation of the physical functions of the elderly, the monitoring of the indicators of the elderly in this scenario using smart home technology alone cannot meet the actual demand, and it is also necessary to provide the elderly with some active daily operation services, such as when the elderly are tired and lying on the sofa, the system takes the initiative to send a glass of water for the elderly [6–7]. Although the smart home technology has a strong sensing ability, but lack of implementation and mobile ability, cannot provide the elderly with the above services. In view of the above problems, some researchers propose to introduce elderly care robots to make up for the shortcomings of the smart home operation ability, used to build a "smart home + elderly care robots" model of home care [8–10]. The biggest advantage of elderly care robots is that they have strong operating ability and mobility, but they also have some shortcomings, such as limited sensing ability and the inability to monitor the surrounding environment throughout the day. Therefore, the integration of smart home technology and elderly care robot technology can combine the advantages of the two, giving full play to the all-round sensing ability of smart home and the strong execution ability and mobility of elderly care robot, so as to provide the elderly with more comprehensive home care services [11–12]. In the fusion scenario of smart home and elderly care robot, due to the many types of devices and data and the complexity of the home environment, in order to provide the elderly with more comprehensive home care services, the system needs to have a certain degree of knowledge fusion and service task reasoning ability, and based on this, the tasks that need to be carried out on the basis of planning. In addition, the system assigns the elderly care robot in the process of performing tasks will face many real-time changes in the situation, such as the occurrence of some emergencies, so the service robot also needs to have a certain degree of real-time task planning capabilities [13–15].

With the continuous progress of science and technology, service robots among the emerging intelligent assistive products are beginning to become the key research direction of home care assistive products. Literature [16] developed the Robot Integrated Smart Home (RiSH) software and designed two underlay applications, human localization and tracking based on particle filtering and human activity recognition based on Dynamic Bayesian Networks, and verified the capability of the designed underlay applications in monitoring and assisting the residents through the RiSH test platform, which provides reference value for the research and development of elderly care assistive technology. Literature [17] proposes a new co-design toolkit to safeguard the value of healthcare interventions by linking the robot's capabilities to known geriatric factors in order to unlock the limitations of functional stagnation and the disconnect between the robot platform and the intervention design, and also discusses the application of the co-design toolkit to ageing-in-place robots. Literature [18] proposes a new implementation of social robotics for sustainable human engagement in home care services for aging populations, which can address caregiver shortages by reducing isolation of older adults and promoting better physical and mental health outcomes. Literature [19] attempted to design a heterogeneous multi-robot system containing a small mobile robot and a home mobile manoeuvring robot, which was validated through a real-life test environment, which empowers older adults to be autonomous in their homes and have a good quality of life.

In addition, the gesture recognition technique used in the literature [20] develops a robot guided by an older person and monitored by a caregiver, and the usefulness of the developed robot is verified through caregiving robotics service experiments, which not only provides emotional and psychological services to frail and infirm older people living at home, but also helps to protect human dignity and personal information. Literature [21] focuses on the architecture and software design of service robots in elderly care scenarios, proposes the use of an environmentally assisted living (EAL) system to integrate service robots with sensor networks and user monitoring, and evaluates the performance and acceptability of elderly care service robots through testing with real end users. Literature [22] designs a social robot system that can provide assistive tasks for home care of patients with mild cognitive impairment, and validates the reliability of the proposed robotic system through field experience using the social robot in the home to provide personalised home care support for the elderly. Literature [23] designed a hybrid system applying steady state drive theory and environmental or human stimuli on a robot, and through experiments, it was found that the robot can maintain a steady state for long-term service, which helps to address the growing needs of the modern ageing society.

In this paper, the biomechanical model of the human body is simplified, the biostructural mechanical parameters of the human body are determined, the biomechanical model of the human body is constructed, and the expressions of the kinetic equations in the horizontal, vertical, and torsion dimensions are given. It also systematically explores the change of force state in the intelligent assistive process of nursing robot. The overall structure of the intelligent nursing robot is proposed, which mainly consists of two parts, the robot body and the control system. The body is the actuator of the intelligent nursing robot system, which provides a support platform for the realization of the functions of the control system, and the control system is the central nervous system of the intelligent nursing robot system, which determines the realization of the functions of the intelligent nursing robot and its performance. Finally, through the experimental analysis of the body biomechanical model and the test analysis of the intelligent nursing robot, the actual performance effect of the home-based intelligent elderly care robot is tested.

2. Biomechanically driven elderly care robot design

2.1. Human biomechanical modeling

The human biological model part mainly introduces the spatial geometric simplification relationship between the human body and various parts of the human body during the contact process with the seat, the parameter setting part mainly introduces the main spring damping parameters involved in the established aggregate parameter model, the multidimensional modeling part mainly introduces the kinetic equations of the horizontal dimension, the vertical dimension, and the torsion dimension, and the computation method of the relevant parameters, and the intelligent assistance part of the nursing robot mainly introduces the human-machine kinetic equations between the human body and the nursing robot. The part of nursing robot intelligent assistance mainly introduces the human-machine dynamics equations of human body and nursing robot.

2.1.1. Simplification of human biomechanical modeling

The biological structure of the human body is complex, involving many muscles and bones, and their simplification is beneficial for further research [24,25]. Combined with the simplified human body structure, a spatial geometric model describing the biological structure of the human body can be constructed, which is used to describe the geometric relationship between human body parts in the standing-sitting interaction, and the spatial geometric model is shown in **Figure 1**.

In the constructed spatial geometric model, the human body is regarded as consisting of three rigid bodies, the head and upper body of the human body are regarded as one rigid body (the center of mass of the rigid body is Q_1), the hips and thighs of the human body are regarded as one rigid body (the center of mass of the rigid body is Q_2), and the lower legs and feet of the human body are regarded as one rigid body. The three rigid bodies are flexibly connected by two points, p_1 and p_2.

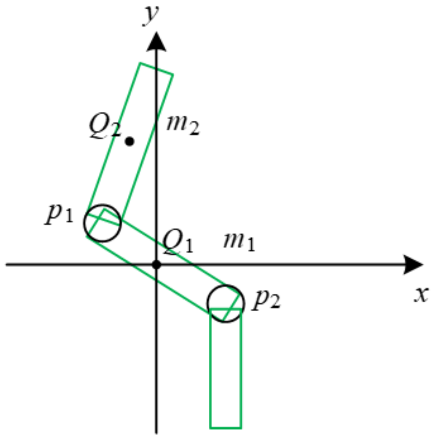


Figure 1. Spatial geometry model.

The rigid bodies can be flattened and rotated between them. Point Q_1 is connected to the seat by two extension springs and one torsion spring. The springs and damping of the seat in the model are fully loaded into the springs and damping of the manikin, i.e., the springs and damping of the seat are 0. The lower legs and feet are considered to be at rest because there is no longitudinal motion and the lateral motion is negligible in process 2. m_1 is the mass of the rigid body of the thigh part and m_2 is the mass of the upper body and torso part, in this paper, N_1 is used to refer to the rigid body of the thigh part and N, to refer to the rigid body of the upper body and torso part.

2.1.2. Parameterization

The interior of the lumped parameter model (A parameter model used to describe the biomechanical characteristics of biomimetic humans) consists of a stack of spring damping, so a large number of spring damping parameters are needed. In the modeling of this paper, the spring damping parameters for the three-point connections in the spatial geometry model of the human body are set for different orientation dimensions as shown in **Table 1**, including three sets of extension springs and extension damping in the horizontal direction, six sets of extension springs and extension damping in the vertical direction, and three torsion springs.

Table 1. Parameter settings for lumped parameter models.

Junction	Q_1	p_1	p_2
Horizontal tension spring	K_{Q_1x}	K_{p_1x}	K_{p_2x}
Horizontal damping	C_{Q_1x}	C_{p_1x}	C_{p_2x}
Stretch the spring vertically$A$	K_{Q_1yA}	K_{p_1y}	K_{p_2y}
Vertical damping$A$	C_{Q_1yA}	C_{p_1y}	C_{p_2y}
Torsion spring	$K_{Q_1\theta}$	$K_{p_1\theta}$	$K_{p_2\theta}$
Stretch the spring vertically$B$	K_{Q_1yB}		
Vertical damping$B$	C_{Q_1yB}		

2.1.3. Horizontal dimension

Consider the biomechanical equations of the mannequin in the horizontal dimension:

$$(m_1 + m_2)\ddot{x}_1 = K_{Q_1x} \times x_1 + C_{Q_1x} \times \dot{x}_1 + f_x \tag{1}$$

x_1 is the transverse displacement of the center of mass of the rigid body on which the thigh is located, $\dot{x}_1$ is the transverse velocity of the center of mass of the rigid body on which the thigh is located, and $\ddot{x}_1$ is the transverse acceleration of the center of mass of the rigid body on which the thigh is located. f_x is the external force in the horizontal direction.

2.1.4. Vertical dimension

Considering the kinetic equations of the human body model in the vertical dimension, the process of motion in the vertical dimension is divided into two phases; in the first phase the human body is subjected to the elastic force and gravity only from the soft springs in the soft part of the seat, while in the second phase the human body is subjected to not only the elastic force and gravity from a constant soft spring, but also from the hard springs in the hard part of the bottom of the seat.

Stage 1 Dynamics Equations:

$$(m_1 + m_2)\ddot{y}_1 = K_{Q_1yA} \times y_1 + C_{Q_1yA} \times \dot{y}_1 - mg + f_y \tag{2}$$

y_1 is the longitudinal displacement of the center of mass of the rigid body on which the thigh is located, $\dot{y}_1$ is the longitudinal velocity of the center of mass of the rigid body on which the thigh is located, and $\ddot{y}_1$ is the longitudinal acceleration of the center of mass of the rigid body on which the thigh is located. f_y is the external force in the longitudinal direction.

Dynamical equations of the second stage:

$$(m_1 + m_2)\ddot{y}_1 = K_{Q_1yB} \times y_1 + C_{Q_1yB} \times \dot{y}_1 - mg + f_y + f_K \tag{3}$$

f_K is a constant elastic force from a soft spring.

2.1.5. Reversing the dimension

Consider the kinetic equations of the mannequin from the torsion dimension:

$$\begin{pmatrix} I_1\ddot{\theta}_1 = M_1 \\ I_2\ddot{\theta}_2 = M_2 \end{pmatrix} \tag{4}$$

I_1 is the moment of inertia of the rigid body on which the thigh is located, M_1 is the moment acting on the rigid body on which the thigh is located, θ_1 is the angle of rotation of the rigid body on which the thigh is located in the pitching direction, and $\ddot{\theta}_1$ is the angular acceleration of the rigid body on which the thigh is located in the pitching direction. I_2 is the moment of inertia of the rigid body on which the torso is located, M_2 is the moment acting on the rigid body on which the torso is located, θ_2 is the angle of rotation of the rigid body on which the torso is located in the pitching direction, and $\ddot{\theta}_2$ is the angular acceleration of the rotation of the rigid body on which the torso is located in the pitching direction.

The formula for M_1:

$$\begin{aligned} M_1 = K_{p_1\theta} \times (\theta_2 - \theta_1) + C_{p_1\theta} \times \left(\dot{\theta}_2 - \dot{\theta}_1\right) - K_{p_2\theta} \times \theta_1 - C_{p_2\theta} \times \dot{\theta}_1 \\ -K_{Q_1\theta} \times \theta_1 - C_{Q_1\theta} \times \theta_1 - M_{p_1m_1} - M_{p_2m_1} \end{aligned} \tag{5}$$

$M_{p_1m_1}$ is the moment of p_1 acting on the rigid body on which the thigh is located, and $M_{p_2m_1}$ is the moment of p_2 acting on the rigid body on which the thigh is located. The formula for M_2:

$$M_2 = K_{p_1\theta} \times (\theta_2 - \theta_1) + C_{p_1\theta} \times \left(\dot{\theta}_2 - \dot{\theta}_1\right) + M_{p_1m_2} \tag{6}$$

$M_{p_1m_2}$ is the moment of p_1 acting on the rigid body on which the thigh is located. The thigh muscle outward force during the stand-sit interaction can be calculated by associating the following equations:

$$cos\,\theta = \frac{{l_{THMUS}}^2 + {l_{THI}}^2 - l_{PAT}^2}{2l_{THUSS}l_{THI}} \tag{7}$$

$$sin\,\theta = \frac{f_y}{F_{THI}} \tag{8}$$

$$f_c = mg - f_y - f_N \tag{9}$$

$$M_1 = f_c \times l_{THI} \tag{10}$$

Assuming that the femur is parallel to the horizontal plane, F_{THI}, f_y, f_N, and f_c represent the thigh muscle force, the component force of the thigh muscle force in the horizontal direction, the support force on the thigh, and the combined external force on the thigh, respectively. θ, θ_1, θ_A, θ_B represent the angle between the thigh muscle and the horizontal plane, the angle of rotation of the rigid body of the thigh in the pitching direction, the angle between the femur and the patella, and the angle between the femur and the horizontal plane, respectively. l_{THMUS}, l_{THI}, l_{PAT} represent the length of the thigh muscle, the length of the femur, and the length of the patella, respectively.

2.1.6. Intelligent assistance for care robots

Before building an intelligent assistive model of the care robot, the force relationship between the human body and the care robot needs to be analyzed. The human body can be regarded as a mass block, and the care robot can also be regarded as a mass block. The human body and the care robot are connected by two groups of spring damping, the first group of spring damping includes the spring damping of the soft part of the human thighs and the spring damping of the soft part of the care robot's chair, while the second group of spring damping includes the spring damping of the hard part of the human thigh bones and the hard part of the care robot's chair. The magnitude of the above spring damping depends on the relative displacement of the human body and the care robot. As the relative displacement changes, the spring damping value changes linearly.

In the first stage of the post-interaction process, the human body is subjected to the spring damping force from the soft part of the care robot's chair and its own gravity, without considering the effect of the second set of spring damping, but only the effect of the first set of spring damping. The care robot, on the other hand, is subjected to the spring damping force from the soft part of the human thighs, its own gravity, and the force exerted on the robot by the motors controlling the robot's lifting and lowering. In the second stage of the post-interaction process, the human body is subjected to the spring damping force from the hard part of the care robot, the maximum value of the spring damping force from the robot in the previous stage, and its own gravity, taking into account that the first stage spring damping force is considered to be a constant and the maximum spring damping force in the first stage, and considering the effect of the second set of spring damping. On the other hand, the care robot is subjected to the spring damping force from the hard part of the human thigh bone, the maximum value of the spring damping from the human in the first stage, its own gravity and the force of the control robot lifting motor on the robot.

Based on the above force analysis to establish the intelligent assistive model of the care robot, the human-machine dynamics equation for the first stage of human-machine interaction is:

$$\begin{aligned} m_{People}\ddot{y}_{People} = K_{soft}\left(y_{People} - y_{Machine}\right) + \\ +C_{soft}\left(\dot{y}_{People} - \dot{y}_{Machine}\right) - m_{People}g \end{aligned} \tag{11}$$

$$m_{Machine}\ddot{y}_{Machine} = K_{soft}\left(y_{Machine} - y_{People}\right) + \\ +C_{soft}\left(\dot{y}_{Machine} - \dot{y}_{People}\right) - m_{Machine}g \tag{12}$$

where in m_{People} is the mass of the human body except for the lower leg, y_{People} is the displacement of the movement of the thigh part of the human body, $\dot{y}_{People}$ is the speed of the movement of the thigh part of the human body, $\ddot{y}_{People}$ is the acceleration of the movement of the thigh part of the human body, $m_{Machine}$ is the mass of the robot, $y_{Machine}$ is the displacement of the movement of the robot, $\dot{y}_{Machine}$ is the speed of the movement of the robot, $\ddot{y}_{Machine}$ is the acceleration of the movement of the robot, K_{soft} is the spring coefficient connecting the human body with the soft part of the robot, C_{soft} is a damping coefficient connecting the human body to the soft part of the robot, and f_{robot} is a force controlling the robot lifting motor on the robot.

The human-machine dynamics equations in the second stage of human-robot interaction are:

$$m_{People}\ddot{y}_{People} = K_{hard}\left(y_{People} - y_{Machine}\right) + \\ +C_{hard}\left(\dot{y}_{People} - \dot{y}_{Machine}\right) - m_{People}g + f_{seg1} \tag{13}$$

$$m_{Machine}\ddot{y}_{Machine} = K_{hard}\left(y_{Machine} - y_{People}\right) + \\ +C_{hard}\left(\dot{y}_{Machine} - \dot{y}_{People}\right) - m_{Machine}g + f_{robot} + f_{seg2} \tag{14}$$

where K_{hard} is the spring coefficient connecting the human body to the hard part of the robot, C_{hard} is the damping coefficient connecting the human body to the hard part of the robot, f_{soft1} is the maximum value of the spring damping force from the robot for the first stage of the human, and f_{sofi2} is the maximum value of the spring damping force from the robot for the first stage of the robot.

2.2. Overall program design of intelligent nursing robot

Based on the human biomechanical model mentioned above, the overall design of the intelligent care robot is proposed. The task of the intelligent care robot is to help patients who are bedridden for a long or short period of time due to old age, disease, or emergencies, etc. to solve the problem of difficult urinary and fecal disposal, and to provide functions such as washing, drying, and bi-directional side-turning after defecation. Since the service objects are special groups, they have different requirements for intelligent care chemical robot, for this reason, the intelligent care robot is required to have different operation modes to choose from. At the same time, the intelligent care robot is required to be compact and delicate.

2.2.1. Main functions and working principle

(1) Main functions

The design of the functions of the intelligent nursing robot should start from the objects it serves. According to the various difficulties they encounter when relieving urination and defecation and the various needs after defecation, and then comprehensively considering the functions of similar products on the market, the function range of the intelligent nursing robot is determined, and then each function is quantified through theoretical analysis or experiment [26,27]. To this end, the project team members of the province of a number of hospitals into the research, at the same time, also appeared on the market related products and customers visited the research, for the deficiencies of the relevant products and users of the additional needs, after the discussion of the project team, and ultimately determine the function of the intelligent care robots, mainly including urinary and fecal flushing, human body private cleaning, warm and cold wind drying, two-way side turn over, etc., and its function block diagram As shown in **Figure 2**.

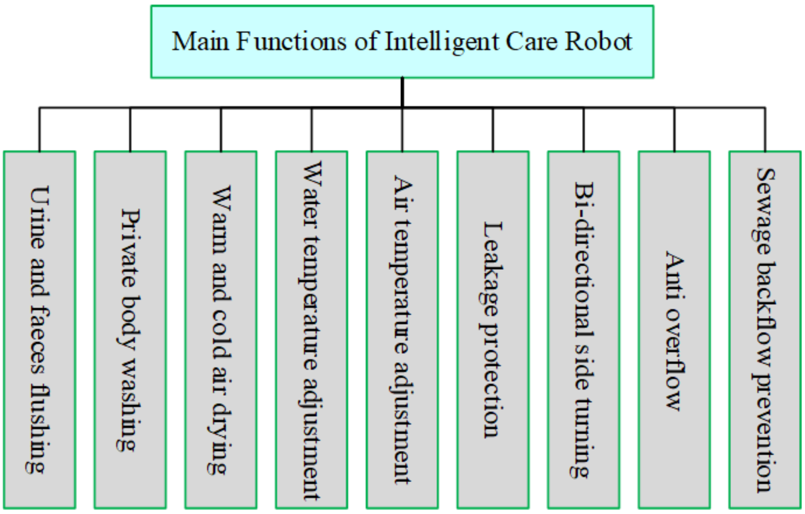


Figure 2. The main function box of intelligent care robot.

(2) Main principle

In view of the special characteristics of the service object, the intelligent nursing robot sets up three different operation modes for bedridden patients to choose from, namely, standby mode, manual mode and automatic mode, and the three modes can be switched arbitrarily between them.

The standby mode is designed to return the intelligent nursing robot to the no-operation state, and at the same time, turn off the related 1/0 port, stool detection module, barometric pressure monitoring module and other energy-consuming devices, so that the whole system is in a low energy consumption state. As the standby mode state, cannot be automatically detected and key to start the function of the care robot, so to prevent children touching the care robot caused by misuse of the work of the robot and so on, to play a protective role.

In manual mode, caregivers and bedridden patients can directly operate the intelligent care robot by pressing the key to select a certain function according to actual needs.

Figure 3 shows the workflow of the urinary and defecation function in the automatic mode, and the relationship between the standby mode, manual mode and automatic mode and each function is shown in **Figure 4**. In the state of automatic mode, the system automatically detects the stool and urine in the commode through the stool detection module and urine detection module, and then, according to the detected results corresponding to the execution of the stool flushing program or the urine flushing program, so as to realize the stool flushing function and the urine flushing function, and the setup of the automatic mode enlarges the scope of service of the intelligent nursing robot.

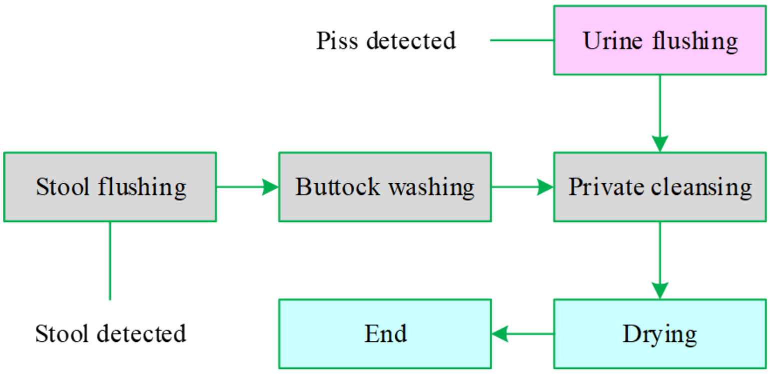


Figure 3. Work flow of defecation function in automatic mode.

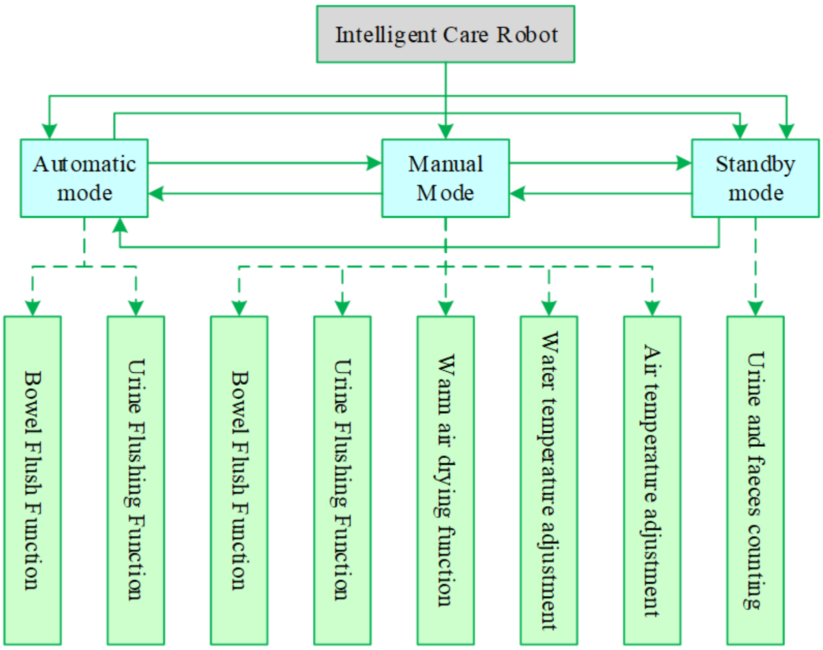


Figure 4. Diagram of patterns and functions.

2.2.2. General design scheme of the robot body

In this research project, ABS (acrylonitrile-butadiene-styrene copolymer) plastic is chosen as the raw material, ABS is a resin with good comprehensive performance, with good impact strength, chemical resistance, dimensional stability, molding and processing. It is odorless, non-toxic and widely used in nursing and medical products. The intelligent nursing robot mainly consists of two parts: the urine-poo processor and the control box, and **Figure 5** shows the schematic diagram of the location of the urine-poo processor and the control box. Since the main body of the urine-poo processor needs to be placed between the thighs, this requires a compact and small structure. According to this requirement, when installing the sensors and designing the circuit boards, the sensors and circuit boards should be arranged in the control box as much as possible. Due to the limited space in the home, hospital and other places, placing the larger objects will affect the human activities, and the current medical equipment are all developing in the direction of miniaturization, which also puts forward the requirements for the volume of the control box, and when laying out all the components, it is necessary to try to arrange them compactly, and to make full use of the space. Good space.

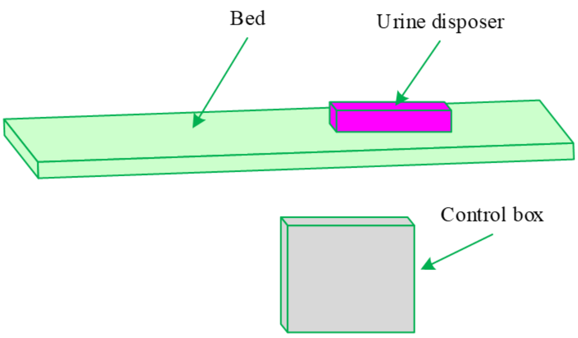


Figure 5. Schematic diagram of the location of the urinal processor and control box.

2.2.3. General design scheme of the control system

Intelligent nursing robot system is a complex and orderly mechatronics system, which mainly includes two parts, robot body and control system. The body is the actuator of intelligent nursing robot system, which provides a support platform for the realization of control system functions, and the control system is the central nervous system of intelligent nursing robot system, which decides the realization of functions and performance of intelligent nursing robot.

By analyzing and dividing the functions of the intelligent nursing robot, the functions realized through the control system are shown in **Figure 6**, and the realization of these functions is mainly through the mutual coordination of software and hardware. The function of the show can be skillfully assisted in the living of the elderly.

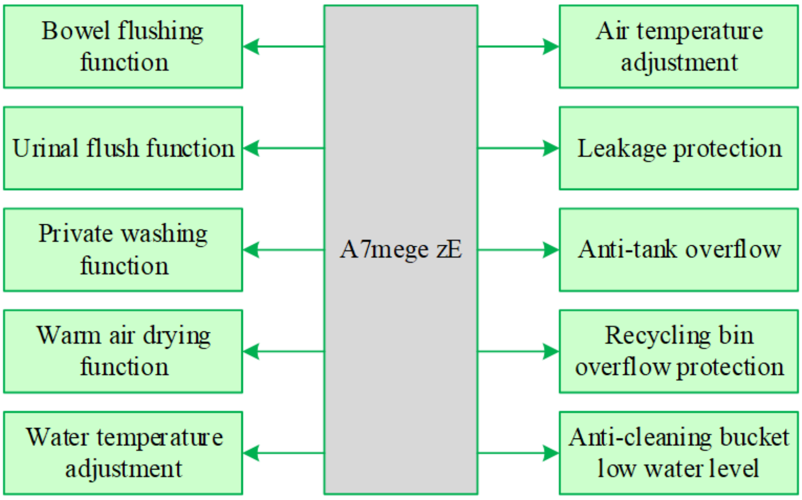


Figure 6. Functional block diagram of the control system.

(1) Hardware

The hardware design of the intelligent nursing robot control system mainly involves the selection of the main controller, the selection of peripheral chips, the hardware circuit design, the determination of the power supply scheme, the selection of components (e.g.: water pump, air pump), etc., of which the hardware circuit design mainly includes the stool detection module, the urine detection module, the barometric pressure monitoring module, the water level detection module, and the temperature detection module. The determination of the main hardware provides the feasibility of the overall hardware program design, and at the same time is conducive to the development process of the control system, shortening the development cycle.

(2) Software

Software design mainly refers to writing programs to control the state of the relevant hardware, so as to realize the corresponding functions. Programming language and programming software are the tools used in software design, selecting the appropriate programming language and programming software can greatly shorten the program development cycle, but also reduce the labor intensity of programmers. When choosing programming language and software, we should first consider whether the programming language and programming software match, and then consider whether they will be complicated to operate.

(a) Programming language selection

Assembly language is the traditional programming language of ATmega128 microcontroller, it is the closest language to machine code, its main advantage is that it occupies less resources, runs faster, and executes more efficiently, due to the fact that the programming in assembly language has to consider the relevant registers of hardware, which leads to low programming efficiency. At the same time, assembly language is very difficult to understand, not good maintenance, poor portability.C language is a high-level language, its main advantages are easy to use and flexible, easy to understand, rich and varied structure, programming efficiency, while having the characteristics of a low-level language, in the development of microcontroller system, there are a lot of desirable features.

(b) Selection of programming software

The programming software used in this project is ICCAVR of Image Craft, which is a C programming software designed for AVR (Automatic Voltage Regulation) microcontroller programs, and requires C programming to comply with ANSI (American National Standards Institute) standards.

(c) The overall idea of programming

In order to make the structure of the whole program clearer and the program operation more stable, when writing the program, it is decided to adopt the design idea of program modularization, based on the function of intelligent care robot, the program is subdivided into relatively independent program modules.

3. Validation analysis of biomechanical modeling and nursing robotics

3.1. Experimental analysis of human biomechanical modeling

3.1.1. Experimental tools

With the help of Anybody human biomechanics software, a human biomechanical model with the exact same dimensions as the subject is built, boundary conditions are set and corresponding loads are applied at the stress points, so as to validate and analyze the human biomechanical model constructed in the previous section. The displacements, accelerations, velocities, and forces of the biomechanical model of each joint of the subject were measured accurately by the sensors as the actual values, and the results calculated by the Anybody human biomechanics software simulation were the theoretical values. Call the initial model of human standing posture in Anybody model library, set the command "Scale by height and weight" to the comment state in the main program page, and turn on the command "Scale by height and weight and fat". Open the external features folder of the human body model under the command column of the scaling tree, and input the size data of each joint of the subject's body into the human body parameter feature variables in order to get the visualized image of the human biomechanical model, and then compare and analyze the simulation results with the actual results of the Anybody software, so as to confirm the validity of the human biomechanical model.

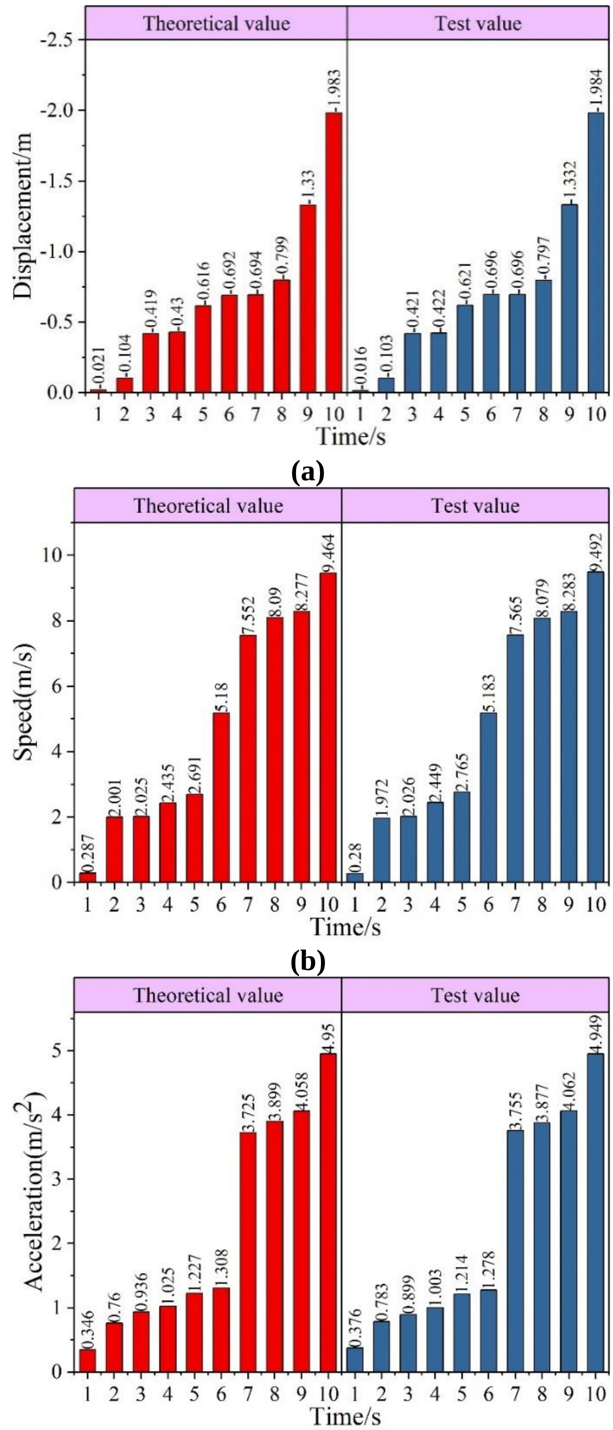
Based on the above tools, the force test of the bionic robot was designed, and the mechanical analysis of a series of human operations was carried out through the people's model library.

3.1.2. Analysis of results

Open the Operations interface, select the Study folder and click on the Initial Conditions command, so that the model maintains a constant attitude to return to the origin, click on the Inverse Dynamics command, call the simulation data of the human biomechanics model in the software and the actual test results of the sensors, and then from the vertical dimension, the intelligence of the care robot, and the assistance to two aspects to the real effectiveness of the human biomechanics model constructed in this paper. Next, we analyze the real effectiveness of the human biomechanical model constructed in this paper from the vertical dimension and the intelligence of the nursing robot, respectively. Specific analysis results are shown below:

(1) Vertical dimension

Based on the theoretical knowledge of the vertical dimension of the human biomechanical model outlined in 2.1.4 above, it can be seen that the vertical dimension is divided into two stages, and only the first stage of the movement process is analyzed here, followed by a comparative analysis of the sensor measurement data (displacement, acceleration, velocity) with the simulation results of the Anybody software, and the results of the vertical dimension validation and analysis are shown in **Figure 7**, in which **Figure 7a–c** respectively are displacement, velocity, and acceleration, the horizontal axis represents time, and the vertical axis represents displacement, velocity, and acceleration, respectively. It can be seen that here set the upward direction as a positive direction, because the human body is only subject to the elastic force from the soft part of the soft spring of the seat and gravity, resulting in the displacement values are negative (with the setting of the reference direction), the difference between the two displacements of 0.001~0.005, are in the error within the tolerable range of other speeds, acceleration and the same reason, confirming that the human body biomechanical model of the validity of the vertical dimension.

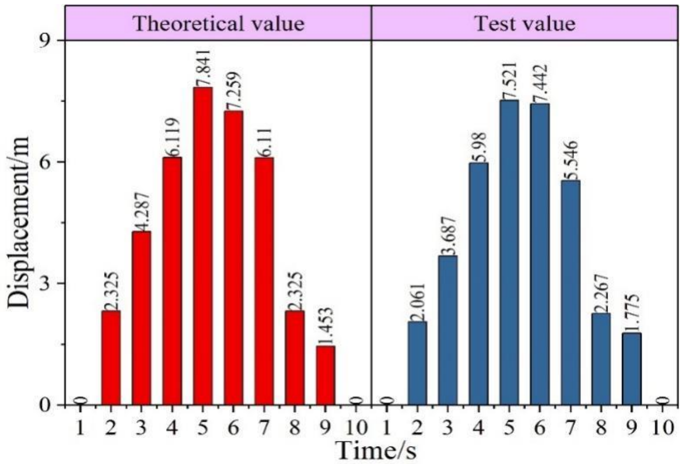


(a) **(b)** **(c)**

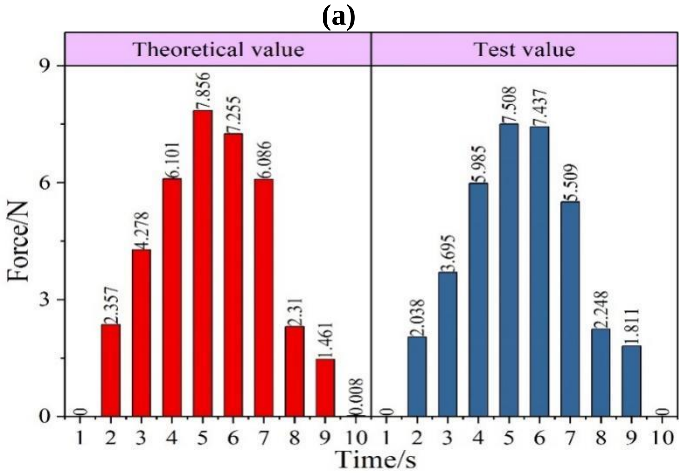
Figure 7. Vertical dimension verification analysis results **(a)** displacement; **(b)** speed; **(c)** acceleration.

(2) Intelligent assistance by nursing robot

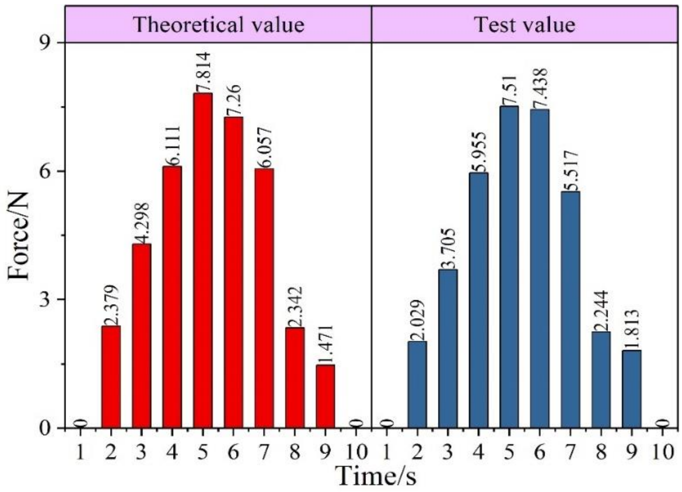
Considering the practicality of the research results, three subjects were arranged to conduct the experiment in the synchronized experiment. According to the above subsection 2.1.6, it can be seen that the nursing robot's intelligent assistance to analyze the human force on the machine (during which it is mainly subjected to its own gravity and the damping force of the spring), and here the same method as in the previous section is taken to verify and analyze the nursing robot's intelligent assistance, and the results of the nursing robot's intelligent assistance analysis are shown in **Figure 8**, in which **Figure 8a–c** are the subjects A, B, and C, respectively. Here the horizontal axis is unchanged (in seconds), while the vertical axis is the human force on the machine (in Nm). It can be seen that, due to the spring damping force and its own gravity, the human force on the machine shows the first rise to the maximum value, and gradually reach the dynamic equilibrium, at this time, the force is 0, a clear and intuitive overview of the nursing robot's intelligent assistive process of the human force changes in the machine, and the most important theoretical value and the test value of both the error is maintained at less than 5%, which comprehensively confirms the nursing robot's intelligent assistive The feasibility of the nursing robot's intelligent assistance is fully confirmed. These results demonstrate the effectiveness of nursing robots in the nursing process of the elderly, and their characteristics can fully care for the care of the care.



(a)



(b)



(c)

Figure 8. Intelligent assisted analysis of nursing robot **(a)** subject A; **(b)** subject B; **(c)** subject C.

3.2. Intelligent care robot test analysis

3.2.1. Test environment

Home wisdom elderly care robot development side of the environment for windows 11 64-bit machine, compatible with windowsXP system, burn program software used is a company's stc-isp-15xx-v6.85N. Robot test site environment for the ordinary family indoor, the ambient temperature between 10 ℃ to 40 ℃, a number of terrain conditions. When the elderly care robot test environment deployment is completed, open the elderly care robot, the robot normal power on and run without any error report, indicating that the situation is all normal, you can start the test of each module driver.

3.2.2. Detection steps

(1) Function test

Home wisdom elderly care robot test analysis, here to the nine functional modules in the urinary and fecal flushing as an example, its urinary and fecal flushing function testing steps are as follows

(a) The robot is energized and presses the start button to enter the working state.

(b) Detect the level of water and sewage bucket, when the level of the two buckets is normal, start to detect the patient's urine and feces, otherwise, an alarm tone will be emitted and the corresponding alarm light will be lit, prompting the caregiver to dump the sewage or fill up the clean water.

(c) When the sensor detects the signal, it will judge whether it is stool or urine according to the signal transmitted from the sensor and enter the corresponding flushing process. Flushing process, the water pump and the vacuum pump to cooperate, together to complete the flushing work. Water pump from the clean water barrel pump out clean water flushing bucket, vacuum pump negative pressure, the use of negative pressure will be flushing sewage discharged into the dirt bucket. The two types of defecation flushing work is only used in the water pipeline and processing time is different, the implementation of the process is not fundamentally different. At the end of the testing session, the intelligent nursing care robot will use hot water and hot air to wash and dry the patient's body. Intelligent nursing care robot control system cleaning and drying process: cleaning valve open, pump work, pump out clean water to clean the patient, vacuum pump using negative pressure to clean sewage discharged into the dirt bucket, fans and heating pads began to work on the body of the cleaned patient drying. At the end of the cleaning and drying session, the machine returned to the detection link to detect urine and feces.

(2) Nursing robot control system performance testing

Performance testing cannot be handled manually, and performance testing tools must be borrowed to simulate user operation of the care robot control system in order to complete performance testing. Especially when simulating large-scale users for stress testing, the method of increasing the number of concurrent users can be adopted until the performance target is reached. During the performance test, it is necessary to focus on the response speed and CPU occupancy of the care robot control system in order to obtain the final test results.

3.2.3. Test results

(1) Functional test results

The results of the urinary and fecal flushing function test of the home wisdom elderly care robot are shown in **Table 2**, where the output of 1 indicates correct detection, and the output of 0 indicates incorrect detection, and the experiment uses small pieces of playdough to simulate stool, and the concentration of 0.3% ammonia solution to simulate urine to carry out 50 simulation experiments for each test. Based on the data in the table, it can be seen that in the 50 times of simulated experimental detection, the number of correctly detected stool is 47, while the number of correctly detected stool is 47, which summarizes that the correct rate of urinary and fecal flushing detection of the home-based intelligent elderly care robot is 0.94 (47/50 = 0.94), 0.98 (49/50 = 0.98), and the correct rate of detection is greater than 0.90, which verifies that the home-based In addition, the home-based intelligent elderly care robot has realized the interconnection with the cloud, and is able to upload data or send commands from the cloud to control the home-based intelligent elderly care robot to perform the corresponding operations, which further reflects the intelligentization of the home-based intelligent elderly care robot, and is able to better meet the needs of the elderly in elderly care.

Table 2. Test result of urine and feces flushing function of nursing robot.

Test frequency/N	Stools	Piss	Test frequency/N	Stools	Piss
1	1	1	26	1	1
2	1	1	27	1	1
3	1	1	28	1	1
4	1	1	29	1	1
5	1	1	30	1	1
6	1	1	31	1	1
7	1	1	32	1	1
8	1	0	33	1	1
9	1	1	34	1	1

Table 2. (*Continued*).

Test frequency/N	Stools	Piss	Test frequency/N	Stools	Piss
10	0	1	35	1	1
11	1	1	36	1	1
12	1	1	37	1	1
13	1	1	38	0	1
14	1	1	39	1	1
15	1	1	40	0	1
16	1	1	41	1	1
17	1	1	42	1	1
18	1	1	43	1	1
19	1	1	44	1	1
20	1	1	45	1	1
21	1	1	46	1	1
22	1	1	47	1	1
23	1	1	48	1	1
24	1	1	49	1	1
25	0	1	50	1	1

(2) Performance test results of the nursing robot control system

Performance is an important part of the system, and the appropriate performance indicators have been set in the requirements phase, and these are the focus of attention in the performance testing phase. If the test results do not meet the set targets, the care robot control system cannot be applied to elderly care activities. This will not only fail to improve the efficiency of the care service, but also reduce the efficiency, so performance testing must be conducted before deployment, and the care robot control system can be applied to the elderly care program only on the basis of the results of the performance test and the demand objectives. In the testing process, LoadRunner software is mainly used to simulate the test, according to the performance requirements, it needs to meet the concurrent access of 1000 users, and the results of the performance test of the nursing robot control system are shown in **Table 3**. Based on the results in the table, it can be seen that the response speed of the control system is controlled within 5 s, and the CPU occupancy rate does not exceed 30.00%, the response speed and CPU occupancy rate are within a reasonable range, which indicates that the designed nursing robot control system is able to satisfy the user's needs for home-based intelligent elderly care.

Table 3. Performance test result.

Concurrent number of users	Response speed (seconds)	CPU usage (%)
100	2.55	5.29
200	2.72	6.03
300	2.92	7.78
400	3.14	12.3
500	3.52	14.81

Table 3. (*Continued*).

Concurrent number of users	Response speed (seconds)	CPU usage (%)
600	4.19	18.13
700	4.32	21.13
800	4.56	22.41
900	4.62	24.81
1000	4.96	29.25

4. Conclusion

In this paper, we first set the biomechanical parameters of each joint of the body of the elderly, construct a human biomechanical model according to the principle of kinetic analysis, divide the model into three dimensions: horizontal, vertical, and torsion, and explore the change of the force state in the process of intelligent assistance for the nursing robot. Based on the human biomechanical model, the overall design scheme of the intelligent nursing robot is formulated, and the corresponding hardware and software are synthesized to jointly complete the design task of the intelligent nursing robot. The error between the theoretical and actual values of displacement, velocity and acceleration in the vertical dimension of the human biomechanical model is kept within 5%, and the rationality of the model is verified. The error between the theoretical and actual values of the human-machine force in the intelligent assistance process of the nursing robot is no more than 5%, which accurately reflects the change of the human-machine force in the intelligent assistance process of the nursing robot. The correct rate of urinary and fecal flushing detection of the home intelligent elderly care robot is 0.94 (47/50 = 0.94), 0.95 (49/50 = 0.98), while the response speed of the control system is controlled within 5s, and the CPU occupancy rate is not more than 30.00%, and all the indexes of the care robot are within a reasonable range. The home wisdom nursing care robot designed in this paper is able to perform the nursing care tasks well, and has a driving role in the development of the field of nursing care intelligence.

Author contributions: Conceptualization, YG and XP; methodology, YG; software, YG; validation, YG, XP and MC; formal analysis, YG; investigation, YG; resources, YG; data curation, YG; writing—original draft preparation, YG; writing—review and editing, YG; visualization, YG; supervision, YG; project administration, YG; funding acquisition, XP. All authors have read and agreed to the published version of the manuscript.

Funding: Subject l: The Research and Practice Project of Higher Education Reform in Henan Province in 2024, number: 2024SJGLX0861. Subject 2: School-based key project of Hebi Vocational and Technical College in 2024, number: 2024-KJZD-003. Subject 3: 2023 School level innovation team, number: 2023ZK04.

Ethical approval: Not applicable.

Conflict of interest: The authors declare no conflict of interest.

References

1. Sapci, A. H., & Sapci, H. A. (2019). Innovative assisted living tools, remote monitoring technologies, artificial intelligence-driven solutions, and robotic systems for aging societies: systematic review. JMIR aging, 2(2), e15429.
2. Vercelli, A., Rainero, I., Ciferri, L., Boido, M., & Pirri, F. (2018). Robots in elderly care. DigitCult-Scientific Journal on Digital Cultures, 2(2), 37-50.
3. Tanabe, S., Saitoh, E., Koyama, S., Kiyono, K., Tatemoto, T., Kumazawa, N., ... & Kanada, Y. (2019). Designing a robotic smart home for everyone, especially the elderly and people with disabilities. Fujita medical journal, 5(2), 31-35.
4. Lim, M. J., Song, W. K., Kweon, H., & Ro, E. R. (2023). Care robot research and development plan for disability and aged care in Korea: A mixed-methods user participation study. Assistive Technology, 35(4), 292-301.
5. Abou Allaban, A., Wang, M., & Padır, T. (2020). A systematic review of robotics research in support of in-home care for older adults. Information, 11(2), 75.
6. Tröbinger, M., Jähne, C., Qu, Z., Elsner, J., Reindl, A., Getz, S., ... & Haddadin, S. (2021). Introducing garmi-a service robotics platform to support the elderly at home: Design philosophy, system overview and first results. IEEE Robotics and Automation Letters, 6(3), 5857-5864.
7. Tokunaga, S., Tamamizu, K., Saiki, S., Nakamura, M., & Yasuda, K. (2017). VirtualCareGiver: Personalized smart elderly care. International Journal of Software Innovation (IJSI), 5(1), 30-43.
8. Ma, C., Guerra-Santin, O., & Mohammadi, M. (2022). Smart home modification design strategies for ageing in place: a systematic review. Journal of Housing and the Built Environment, 37(2), 625-651.
9. Majumder, S., Aghayi, E., Noferesti, M., Memarzadeh-Tehran, H., Mondal, T., Pang, Z., & Deen, M. J. (2017). Smart homes for elderly healthcare—Recent advances and research challenges. Sensors, 17(11), 2496.
10. Curumsing, M. K., Fernando, N., Abdelrazek, M., Vasa, R., Mouzakis, K., & Grundy, J. (2019). Emotion-oriented requirements engineering: A case study in developing a smart home system for the elderly. Journal of systems and software, 147, 215-229.
11. Johnson, M. J., Johnson, M. A., Sefcik, J. S., Cacchione, P. Z., Mucchiani, C., Lau, T., & Yim, M. (2020). Task and design requirements for an affordable mobile service robot for elder care in an all-inclusive care for elders assisted-living setting. International journal of social robotics, 12, 989-1008.
12. Yang, G., Pang, Z., Deen, M. J., Dong, M., Zhang, Y. T., Lovell, N., & Rahmani, A. M. (2020). Homecare robotic systems for healthcare 4.0: Visions and enabling technologies. IEEE journal of biomedical and health informatics, 24(9), 2535-2549.
13. Shishehgar, M., Kerr, D., & Blake, J. (2018). A systematic review of research into how robotic technology can help older people. Smart Health, 7, 1-18.
14. Lee, S., & Naguib, A. M. (2020). Toward a sociable and dependable elderly care robot: design, implementation and user study. Journal of Intelligent & Robotic Systems, 98(1), 5-17.
15. Nathan, V., Paul, S., Prioleau, T., Niu, L., Mortazavi, B. J., Cambone, S. A., ... & Jafari, R. (2018). A survey on smart homes for aging in place: Toward solutions to the specific needs of the elderly. IEEE Signal Processing Magazine, 35(5), 111-119.
16. Do, H. M., Pham, M., Sheng, W., Yang, D., & Liu, M. (2018). RiSH: A robot-integrated smart home for elderly care. Robotics and Autonomous Systems, 101, 74-92.
17. Bardaro, G., Antonini, A., & Motta, E. (2022). Robots for elderly care in the home: A landscape analysis and co-design toolkit. International Journal of Social Robotics, 14(3), 657-681.
18. Kok, C. L., Ho, C. K., Teo, T. H., Kato, K., & Koh, Y. Y. (2024). A Novel Implementation of a Social Robot for Sustainable Human Engagement in Homecare Services for Ageing Populations. Sensors, 24(14), 4466.
19. Barber, R., Ortiz, F. J., Garrido, S., Calatrava-Nicolás, F. M., Mora, A., Prados, A., ... & Mozos, Ó. M. (2022). A multirobot system in an assisted home environment to support the elderly in their daily lives. Sensors, 22(20), 7983.
20. Kim, J. W., Choi, Y. L., Jeong, S. H., & Han, J. (2022). A care robot with ethical sensing system for older adults at home. Sensors, 22(19), 7515.
21. Hendrich, N., Bistry, H., & Zhang, J. (2015). Architecture and software design for a service robot in an elderly-care scenario. Engineering, 1(1), 027-035.
22. Di Napoli, C., Ercolano, G., & Rossi, S. (2023). Personalized home-care support for the elderly: a field experience with a social robot at home. User Modeling and User-Adapted Interaction, 33(2), 405-440.

23. Yang, C. Y., Lu, M. J., Tseng, S. H., & Fu, L. C. (2017, September). A companion robot for daily care of elders based on homeostasis. In 2017 56th Annual Conference of the Society of Instrument and Control Engineers of Japan (SICE) (pp. 1401-1406). IEEE.
24. Paulina Działak,Jacek Karliński & Paweł Maślak. (2024). Development of a Biomechanical Human Model for Safety Analysis of the Operators of Self-Propelled Mining Machines. Acta Mechanica et Automatica(2),333-340.
25. Vijayan Kiran,Bhardawaj Sono,Sharma Rakesh Chandmal, Sharma Sunil Kumar,Gopala Rao LVV & Vashist Amit. (2023). Modeling of biomechanical human body model for seat to head transmissibility analysis.Noise & Vibration Worldwide(2-3),62-74.
26. Zhang Chenyu & Marlene Rodrigues. (2021). Application of Kawakita Jiro/Analytic Hierarchy Process/Quality Function Development Integrated Ankle Rehabilitation Nursing Robot in Orthopaedics. Journal of Medical Imaging and Health Informatics(9),2315-2323.
27. Jiaxin Wang,Huanyu Deng,Yulong Wang,Jiexin Xie,Hui Zhang,Yang Li & Shijie Guo. (2024). Multi-sensor fusion federated learning method of human posture recognition for dual-arm nursing robots. Information Fusion102320-.