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Research and Prospect of Intelligent Bathing Services for the Disabled Elderly

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Abstract*—*With the intensification of the aging trend of the population, the number of disabled elderly people is increasing, and their daily life care has become a social problem that needs to be solved urgently. As an indispensable part of the daily life of the disabled elderly, bathing often faces many difficulties due to the decline of physical functions. The emergence of intelligent bathing services provides a safe, comfortable and convenient bathing solution for the disabled elderly. This paper reviews the current situation of bathing for the disabled elderly, discusses the research status of intelligent bathing services, and looks forward to its future.

Keywords*—*Disabled elderly, Ageing, Smart bathing, Bathing.

I. INTRODUCTION

With the acceleration of the global aging process and the in-depth evolution of the demographic structure, the care demand of the disabled elderly group is showing a geometric growth trend[1]. According to statistics, the number of elderly people over 60 years old in China has reached 267 million, of which more than 40 million are disabled or semi-disabled, and it is expected to exceed 77 million by 2030[2].

In this context, the contradiction between supply and demand of basic care has become increasingly prominent, and safe bathing, as the core life demand[3], has become a key bottleneck in the field of elderly care. According to the World Health Organization, more than 90% of the elderly are at risk of bathing disability, and a sample survey of the urban and rural elderly population in China shows that 90.8% of them are unable to take care of themselves when taking a bath, of which 26.6% are completely dependent on others[4].

This grim reality exposes the limitations of traditional care models: the high cost of manual care, insufficient privacy protection, and low degree of operational standardization are becoming increasingly prominent, especially under the dual pressure of resource shortage and weakened family care capacity in China's elderly care institutions, and the contradiction between the demand and supply of bathing for the disabled elderly continues to intensify[5].

In view of the above problems, this paper carries out the research and prospect of intelligent bathing services for the disabled elderly. Based on the comparison of domestic and foreign research, this paper systematically sorts out the current situation and technical feasibility path of bathing for the disabled elderly, and puts forward the future development direction from the three dimensions of technological innovation, service ecological reconstruction and policy support, and expects that the innovative research and development of the intelligent bathing service system will provide new ideas for solving the dilemma of elderly care, and provide theoretical support and practical reference for the construction of a warm smart elderly care paradigm.

II. THE CURRENT SITUATION OF BATHING FOR THE DISABLED ELDERLY

A. Definition of disabled elderly

According to the age stratification guidelines developed by the World Health Organization, the age group of 60 to 74 years is defined as young and elderly, 75 to 89 years of age is the elderly, and over 90 years of age is defined as long-lived[6].

The so-called disabled elderly group refers to elderly individuals who have impaired their ability to perform basic daily life activities due to natural decline of physiological functions or the influence of chronic diseases, and need assistance from others or partially or completely rely on caregivers in basic behaviors such as getting out of bed, cleaning the body, putting on and taking off clothes, and going to the toilet to excrete[5].

B. The current situation of bathing for the disabled elderly

Due to the long-term effects of chronic diseases, older age groups are among the first to experience loss of bathing ability[7]. Epidemiological data from the United States show that in the past 6 years, 58.4% of the elderly population has bathing self-care disorders, and the degree of disability is particularly significant in the frail and ultra-elderly groups.

The relevant authorities will decide whether to provide home assistant services according to the ability of the elderly to bathe[8], so the cleaning and care needs of this group are better guaranteed. For safety risk factors in the use of bathroom facilities in older adults, a prescribing model for bathing devices exists in the United States, based on the mobility of older adults, which can be used to evaluate bathing equipment related to mobility and support[9].

By collecting the actual feedback of elderly users on the adaptability, convenience of operation and comfort of the equipment, and assisting them to select the auxiliary tools with the highest adaptability, the bathing safety and experience satisfaction of the elderly group were effectively improved.

According to the data of the 2003 one-time sample survey of the elderly population in urban and rural areas of China, 90.8% of them lacked the ability to complete bathing independently in the assessment of six basic living skills:

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eating, putting on and taking off clothes, transferring beds and chairs, toileting, body cleaning, and indoor mobility, of which 26.6% had completely lost their ability to take care of themselves, and 9.8% had significant operational difficulties[2].

Xu Jiaming's structural analysis of the long-term care needs of urban elderly groups further pointed out that among the dimensions of various daily care needs, the need for physical cleaning assistance ranked first[10].

In addition, according to the study of day care services for the disabled elderly in nursing institutions, bathing care accounts for 8.21% of the average daily workload in the allocation of total working hours of life care, but it is difficult to meet the bathing needs of the disabled elderly due to the insufficient allocation of human resources and imperfect bathing facilities in nursing institutions[11].

C. Difficulties and challenges in bathing for the disabled elderly

In daily activities, elderly individuals first lose their ability to bathe independently due to the multiple components involved in bathing tasks, as disability in any single component compromises their ability to complete the entire process[12].

Relevant studies have established a cleaning behavior evaluation system through action decomposition experiments, refining the full bathing process into two assessment dimensions: upper limb range of motion (encompassing reach capabilities to the top of the head, contralateral acromion, abdomen, lateral waist, lower back, buttocks, and lower limbs) and trunk coordination (such as posture adjustments like bending and turning).

These studies emphasize that autonomous cleaning is only achievable when individuals retain basic motor abilities across all components[13].

However, due to declining physical coordination and adaptive capacities, older adults require significantly more time and energy to perform cleaning tasks such as dressing, scrubbing, and changing body positions. Those with moderate physical limitations necessitate varying degrees of human assistance.

Research on non-severely disabled elderly populations in the United States reveals that over half experience disability in at least one component, while nearly one-third suffer from multi-component disabilities[14]. This contradiction between the progressive deterioration of motor functions and the complexity of hygiene needs constitutes a critical challenge demanding urgent attention in the field of disabled elderly care.

III. Research Status of Intelligent Bathing Assistance Services at Home and Abroad

A. Research on Intelligent Bathing Assistance in the United States

Driven by the rapid economic growth and optimized social security system in the 20th century, the elderly care product industry in the United States has rapidly developed, alongside comprehensive welfare policies for seniors. Advanced technological progress is particularly evident in intelligent bathing assistive devices for the elderly.

The U.S. senior care model has led to the design of assistive devices that primarily support caregivers in partial tasks. For instance, the "Cody" care robot developed by the Georgia Institute of Technology is equipped with a multi-joint robotic arm and specialized cleaning modules. Through machine vision and laser positioning systems, it intelligently identifies cleaning areas and performs precise foam-based cleaning operations.

This "human-robot collaboration" design paradigm profoundly reflects the integrated application of assistive technologies within the American senior care service system[15].

B. Research on Intelligent Bathing Assistance in Japan

As one of the earliest countries to enter a hyper-aged society, Japan has established a comprehensive age-friendly technological system in the field of bathing care.

Bathing transfer, a critical step in the process, poses significant risks if mishandled, potentially increasing hospitalization and mortality rates[16]. In response, Japan has innovated multimodal transfer assistance systems tailored to different bathing postures, including standing, sitting, and lying transfers. These systems are further categorized by transfer methods: walk-in transfers, lift-assisted transfers, sliding rail transfers, and wheelchair transfers.

Additionally, Japan has developed fully automated bathing systems that enhance user experience. Most such systems adopt semi-enclosed ergonomic designs, integrating skin cleansing, water temperature control, warm air drying, and automated hair washing functions.

Notably, these systems pioneered automated hair washing, achieving full-process automation from foam application to water rinsing, creating a new paradigm for intelligent senior bathing equipment[15].

C. Research on Intelligent Bathing Assistance in China

China's elderly bathing assistance device sector remains in the technological transformation phase, with an accelerated development of independent research systems.

While multiple innovative achievements have emerged in mechanical system design, most remain at the structural design stage. Several research institutions have developed novel assistive devices tailored to domestic needs, including ergonomics-based standing support systems and integrated bathroom care robots[17].

For example, the assisted standing device developed by Fu D's team[18] and the human-interactive care robot by Pei X's team[19] demonstrate cross-disciplinary integrated innovation. The collaborative design of a hygiene care robot combines an assisted standing system, hair washing module, body scrubbing system, water recycling system, and vital signs monitoring system[20].

IV. Future Prospects

In response to the escalating care needs of disabled elderly in an aging society, intelligent bathing assistance services face vast development potential. In the future, these services will

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advance in three primary directions, achieving systematic breakthroughs through technological innovation, service ecosystem construction, and social support systems to meet growing demands.

A. Technological Innovation: Building a Full-Chain "Sensing-Decision-Service" Intelligence

A three-dimensional environmental sensing network will be established by integrating millimeter-wave radar, thermal imaging sensors, and flexible electrode arrays. Millimeter-wave radar precisely captures body movement trajectories, thermal imaging monitors skin temperature distribution, and flexible electrodes non-invasively collect physiological signals. Combined with AI algorithms, a multi-parameter fusion model will be created. When the system detects abnormal heart rate fluctuations or uneven body temperature distribution, it automatically triggers equipment linkage mechanisms, adjusts water temperature to preset safety thresholds (e.g., 37±1℃), and activates anti-slip floor heating and emergency lighting modules, forming a closed-loop "risk warning-equipment response-status reset" control.

Pneumatic muscle-driven flexible robotic arms with nano-scale biocompatible coatings and embedded multi-dimensional force-torque sensors will be developed. Through deep learning, ergonomic models will enable adaptive joint range-of-motion adjustments for different body types, achieving force-position hybrid control (force control precision up to 0.5N) during dressing/undressing. The interface adopts a multi-modal fusion framework, with speech recognition supporting continuous dialect library expansion, gesture recognition integrating depth cameras and myoelectric signal analysis, and brain-computer interfaces using steady-state visual evoked potential (SSVEP) paradigms to provide non-verbal operation channels for late-stage Alzheimer's patients.

Multi-physics coupled digital twins will integrate biomechanical, heat transfer, and psychological stress models. Personalized prediction models trained on historical bathing data (including skin capacitance, muscle tension, etc.) will preemptively adjust pressure distribution on support surfaces when predicting pressure ulcer risks and trigger aromatherapy systems upon detecting anxiety. The digital twin platform also supports multi-user collaborative decision-making, allowing remote parameter adjustments by caregivers and generating traceable blockchain service records.

B. Service Ecosystem: Creating a "Home-Community-Institution" Three-Dimensional System

Promote "smart bathing pods + mobile service robots" in home settings, with pods integrating auto-disinfection and water quality monitoring, and robots equipped with retractable arms for assisted cleaning. Community-level "health bathing hubs" will feature multifunctional pools (with hydrotherapy and medicinal bath functions), rehabilitation zones, and social interaction spaces, interconnected with primary healthcare data systems. Collaborate with tertiary hospitals to develop postoperative care packages, including zero-transfer bathing solutions for hip surgery patients with wearable vital sign monitors for seamless post-hospital care transitions.

Develop a multi-dimensional assessment system covering 12-lead ECG and balance tests for physiological indicators, AI-driven facial expression recognition for mental state evaluations, and environmental adaptability models considering home layouts and aging-friendly renovations. Extend services to the full "prevention-intervention-rehabilitation" cycle, offering seasonal skin care solutions (e.g., winter dryness warning systems), traditional Chinese medicine steaming modules, and aquatic therapy courses with rehabilitation departments, forming "bathing assistance + health promotion" value-added packages.

Establish a "Smart Bathing Assistant" vocational certification system, including courses on gerontology, smart device maintenance, and service ethics, with VR simulations for disabled elderly care scenarios. Partner with vocational colleges for customized training programs to cultivate composite talents skilled in equipment debugging, health assessments, and emergency rescue. Create a digital service quality monitoring platform using wearable devices to record processes and generate improvement reports based on user feedback.

C. Social Support: Establishing a "Policy-Industry-Ethics" Synergistic System

Advocate for inclusion of smart bathing assistance in long-term care insurance coverage, with reimbursement caps at 80%. Establish an "aging-friendly renovation fund" providing 50% subsidies for smart bathing installations and tax incentives for equipment leasing enterprises. Enact regulations on elderly biometric data protection, mandating minimal data collection principles and hierarchical access mechanisms, with joint credit penalties for violations.

Encourage universities to form "Smart Bathing Innovation Alliances" and launch key technology projects (e.g., flexible sensor material R&D). Establish national testing and certification centers with 23-indicator group standards covering device safety and ergonomics. Create a technology commercialization platform offering government procurement priority to certified enterprises, fostering a billion-dollar industrial cluster.

Develop an intergenerational "Silver Age Mutual Aid" system where healthy elderly earn service credits through volunteering. Design multi-sensory therapy programs with customized aromatherapy (e.g., lavender for sleep, citrus for energy) and nostalgic music during bathing. Establish a psychological assessment system to initiate crisis interventions for depression-prone individuals, using dynamic lighting to create soothing environments, integrating technology with humanistic care.

Through synergistic evolution across technology, services, and safeguards, intelligent bathing assistance will transition from "functional replacement" to "value empowerment," becoming a critical pillar for proactive aging responses. Future priorities include resolving ethical boundaries and cost-sharing mechanisms, building a compassionate smart elderly care paradigm guided by technology for social good.

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