

Yixing AI Exoskeleton-Multi-modal Intelligent Walking Ark for All Scenarios

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Abstract: In the context of accelerating global aging and the expanding population of individuals with physical disabilities, the demand for efficient assistive devices has become increasingly urgent. Addressing this pressing need, our project integrates AI technology with medical applications to develop an intelligent exoskeleton equipped with a GSM communication module and a dual-mode Beidou + GPS positioning unit. This innovative device not only enables precise posture adjustment and active safety protection but also collects real-time physiological data and gait characteristics, automatically generating rehabilitation assessment reports. To ensure technology truly serves people, we have established a user profiling database leveraging big data, enabling modular design and personalized customization for versatile applications in hospitals, communities, and homes. Through industry-academia-research collaboration, our integrated online-offline sales strategy aims to achieve financial balance by the third operational year. We are committed to helping mobility-impaired individuals regain their freedom of movement and injecting new momentum into the development of intelligent walking assistive devices.

Keywords: AI exoskeleton; Full-scenario adaptation; Multimodal fusion; Rehabilitation assistance

Online publication: March 31, 2026

1. Research background and current status

1.1. Research background

According to the 2023 data from the World Health Organization, approximately 16% of the global population (1.3 billion people) suffer from severe mobility impairments. China has nearly 25 million people with physical disabilities, including children with congenital disabilities, middle-aged and young adults with accidental disabilities, and elderly individuals with functional decline^[1]. Such populations experience a decline in quality of life due to limited mobility, imposing a heavy burden on families and society.

The limitations of traditional mobility aids are evident: crutches rely excessively on upper limb force, making them unsuitable for individuals with physical frailty; prolonged use of wheelchairs can lead to muscle atrophy and restrict mobility scenarios^[2]. With the deepening integration of artificial intelligence in the medical field, intelligent mobility devices are emerging as a key direction to overcome these limitations^[3].

1.2. Research status

1.2.1. Current status of smart exoskeleton technology

Globally, Honda's exoskeletons primarily serve industrial heavy-load applications, while Ekso Bionics focuses on medical rehabilitation. However, both face common challenges like high costs and lengthy customization cycles. In contrast, domestic counterparts mostly remain at the basic mechanical-assistance stage, lacking both intelligent features and adaptability to diverse scenarios. As illustrated in **Figure 1**, Ekso Bionics^[4]' rehabilitation product, vividly demonstrates this industry reality^[5].



Figure 1. Ekso Bionics rehabilitation product.

1.2.2. Limitations of existing technology

- (1) Limited environmental awareness: Most traditional devices rely solely on a single sensor for data collection, resulting in inadequate recognition and navigation capabilities when encountering complex

terrains such as steps or slopes, which may compromise walking safety.

- (2) Poor user experience: The cumbersome operation process and high learning threshold make it less user-friendly for elderly users, reducing their willingness to use the device daily.
- (3) Insufficient adaptability: It is difficult to achieve personalized adaptation for users with different body types and gait characteristics, failing to fully meet diverse usage requirements.
- (4) Fragmented functional scenarios: The functional integration between medical rehabilitation and daily life scenarios is insufficiently seamless. Devices often only meet the needs of a single scenario, making it difficult to support users throughout the entire lifecycle from rehabilitation training to independent living^[6].

1.3. Innovations

The study has deeply integrated AI technology with medical rehabilitation needs, incorporating multimodal sensors, machine learning algorithms, and natural human-computer interaction technologies. Through real-time AI capture of users' muscle tension, gait characteristics, and other physiological states, the device dynamically adjusts support intensity, walking speed, and posture to achieve truly intelligent assisted walking. Simultaneously, the device can connect with mobile terminals or cloud platforms to provide value-added services such as remote monitoring, gait data analysis, and personalized rehabilitation recommendations for healthcare professionals and family members, thereby establishing a closed-loop service system of "device-user-healthcare".

The product's innovation lies in transcending the limitations of traditional walking aids by integrating intelligent features, such as the voice assistant, automatic obstacle avoidance, smart navigation, fall detection, emergency assistance, and health monitoring. This delivers comprehensive, personalized services while enhancing both practicality and safety^[7].

2. System design

2.1. Overall architecture

The WingXing AI exoskeleton system adopts a three-tier architecture of "perception-decision-execution":

- (1) The perception layer integrates 12 types of sensors, including Beidou + GPS dual-mode positioning, infrared mapping, and biosensors, to establish a multi-dimensional data acquisition network.
- (2) Decision-making layer: Using the Raspberry Pi 4B hardware platform, it achieves dynamic adjustment through a self-developed gait recognition algorithm with 92% intent recognition accuracy.

The actuator layer employs a carbon fiber-titanium alloy composite drive structure to achieve lightweight yet high-strength support.

2.2. Performance features

- (1) Multimodal Intelligent Fusion

By integrating data from 12 types of sensors, the system constructs an "environment-human-motion" data network to analyze user intent in real time and dynamically adjust assistive power^[8].

- (2) Rapid Modular Customization

Based on 3D scanning and big data analysis, the modules, such as joint disassembly and support, are separated.

- (3) Full-scenario adaptive control

(a) Medical Rehabilitation: Covers 12 types of abnormal gait correction and generates personalized

- rehabilitation reports;
 - (b) Daily life: emergency obstacle avoidance response, three-level fall protection mechanism;
 - (c) Industrial tourism: Heavy-load assistance with minimal navigation errors in scenic areas ^[9].
- (4) Intelligent Interaction and Remote Monitoring
- Supports dialect recognition and rapid response to voice commands; wireless data transmission to the cloud enables remote participation in healthcare collaboration ^[10].

3. Product Technology Introduction

3.1. Raspberry Pi 4B System

The Raspberry Pi 4B serves as the core control and data processing hub of the entire device, primarily handling the following functions ^[11]:

- (1) Data acquisition and command output: The system receives real-time data from attitude and pressure sensors, processes it, and sends precise commands to the motor driver to dynamically adjust torque, providing users with tailored assistance or support.
- (2) Status Monitoring and Multi-Module Collaboration: Integrates multi-dimensional sensor data, such as posture and pressure to comprehensively monitor the user's physical condition and walking status. Simultaneously, it collaborates with the Beidou + GPS positioning module and GSM communication module to process and store positioning information, and triggers the GSM module in emergency situations to send alarm messages and real-time location to preset contacts.

3.2. Infrared surveying module

The infrared emitter in this module emits a specific infrared beam, typically modulated as pulses or intensity-modulated. When the beam encounters a target object and reflects, part of the reflected light is focused onto the infrared detector through an optical system and converted into electrical signals. The signal processing unit amplifies and filters these signals to calculate the distance between the target object and the module, thereby enabling environmental mapping.

3.3. Pressure sensor

This module's pressure sensor features multiple core functions to accurately detect pressure distribution at the contact points between the user's body and the assistive device. Its key functionalities include:

- (1) Gait Analysis & Dynamic Assistance: By integrating pressure distribution data with other sensor inputs, the system dynamically assesses the user's posture and walking stability in real time, helping to identify movement intentions. It then adjusts motor output accordingly to provide optimal assistance for maintaining balance, ensuring a natural and smooth walking experience.
- (2) Fit Monitoring & Comfort Assurance: The system continuously monitors the device's contact with the body. If it detects excessive tightness, it automatically loosens the fit. Conversely, if the device is too loose, it issues a tightening prompt to ensure comfortable wear and effective assistance.

3.4. GPS and Beidou modules

This module simultaneously receives signals from both Beidou and GPS systems. After processing, it can output precise position, speed, and time information, featuring multiple core functions ^[12]:

- (1) Precise positioning: Provides real-time user location for family members or healthcare professionals to ensure daily safety.
- (2) Auxiliary navigation: Integrated with digital maps, it can plan suitable walking routes for users, particularly in complex or unfamiliar environments.
- (3) Safety Assurance: When an emergency alert is triggered, the system instantly shares your location with pre-set contacts, providing precise coordinates for rescue operations.
- (4) Data support: Record users' movement trajectories and gait data, transmit to Raspberry Pi 4B for analysis, providing data basis for subsequent rehabilitation plan optimization and health management.

3.5. GSM module

The GSM module enables wireless communication via GSM networks using Time Division Multiple Access (TDMA) technology, transmitting and receiving data across different time slots. It encodes and modulates user voice, SMS, or device data, then transmits them to GSM base stations through antennas. Simultaneously, it receives network signals and performs decoding and demodulation. This capability provides a reliable communication link for emergency alerts, remote data transmission, and device control and management^[13].

3.6. Robot-specific steerings

- (1) Dynamic motion control: The servo motor precisely controls rotation angle and force according to system commands, enabling adjustments like force arm angle and leg swing assistance to achieve a more natural and fluid walking posture.
- (2) Stable coordination assurance: During the user's walking process, the rudder receives feedback data from the attitude module and pressure sensor, adjusting the output torque in real time to maintain the balance of the assistive device. This ensures that all components move stably and coordinately, helping the user maintain the correct walking posture.

3.7. Motor drive module

The motor drive module performs three core functions: supplying power and control signals to operate the motor as required for user assistance; precisely regulating speed, direction, and torque to dynamically adjust support force for stable movement; and providing overcurrent and overheating protection to prevent motor damage, ensuring system safety and extending equipment lifespan.

4. Introduction to core algorithms

4.1. Dynamic Time Warping (DTW) algorithm (Core of Gait Recognition)

The similarity between the user's real-time gait sequence and the standard gait sequence in the database is compared to achieve motion intention recognition, as shown in **Figure 2**.

```
import numpy as np

def dtw_distance(standard_gait, realtime_gait):
    """
    计算标准步态序列与实时步态序列的DTW距离
    :param standard_gait: 数据库中的标准步态序列 (shape: [m, n], m为时间步, n为特征维度)
    :param realtime_gait: 传感器采集的实时步态序列 (shape: [k, n], k为时间步)
    :return: 最小距离 (距离越小, 相似度越高)
    """
    m = len(standard_gait)
    k = len(realtime_gait)

    # 初始化距离矩阵
    dtw_matrix = np.zeros((m+1, k+1))
    dtw_matrix[:, 0] = np.inf
    dtw_matrix[0, :] = np.inf
    dtw_matrix[0, 0] = 0
```

Figure 2. Core algorithm code for gait recognition.

4.2. Dynamic Time Warping (DTW) + Hidden Markov Model (HMM) fusion algorithm for motion intent recognition

By combining DTW's sequence matching capability with HMM's state modeling capability, the accuracy of motion intention recognition in complex scenarios (e.g., stair climbing and walking on flat ground) is improved^[14], as shown in Figure 3.

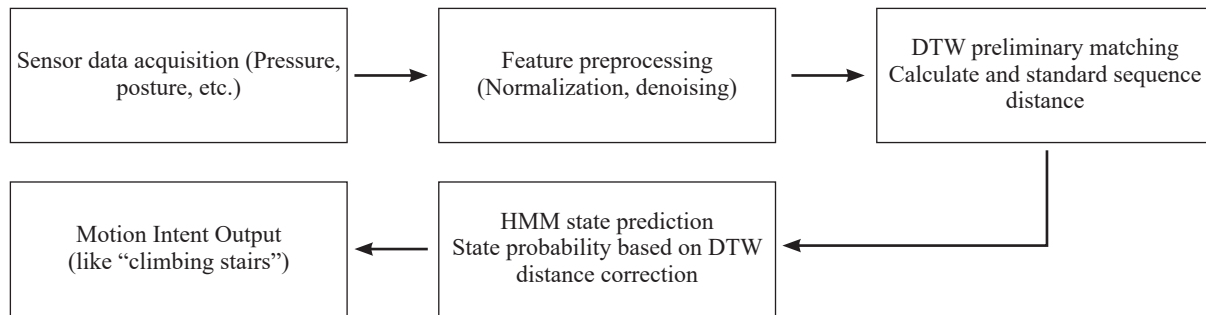


Figure 3. Flowchart of TM+HMM fusion algorithm.

4.3. Federated Learning Algorithm (Global Gait Database Sharing)

Under the premise of protecting user privacy, collaborative training of gait data across multiple regions (e.g., different hospitals and rehabilitation institutions) is achieved to optimize the model, as shown in Figure 3^[15].

5. Conclusion and prospects

The winged AI exoskeleton proposed in this study overcomes the limitations of traditional mobility aids through multimodal intelligent fusion and modular customization, achieving full-scenario adaptive mobility assistance. Experimental results demonstrate that the system exhibits outstanding performance in terrain adaptability and human-machine collaboration, possessing significant medical value and social implications.

In the future, we will further integrate brain-computer interface (BCI) and neural feedback technologies to optimize the data ecosystem closed loop, driving the evolution of intelligent mobility assistance systems from 'passive assistance' to 'intention anticipation-precision assistance', thereby providing more natural and efficient mobility support for individuals with limited mobility.

Funding

College Students' Innovation Training Program

Disclosure statement

The author declares no conflict of interest.

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