

Motion Path Planning of Wearable Lower Limb Exoskeleton Robot Based on Feature Description

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Abstract—Wearable lower extremity exoskeleton robot is a kind of training equipment designed for the disabled or powerless in the lower extremity. In order to improve the environmental adaptability of the robot and better meet the use habits of patients, it is necessary to plan and design the movement path, and a movement path planning model of wearable lower extremity exoskeleton robot based on feature description is proposed, which describes the objects with different wearing frequencies and training intensities. Taking the wearer's natural walking gait as the constraint feature quantity and the control object model, the spatial planning and design of exoskeleton structures such as hip joint, knee joint and ankle joint are adopted, and the traditional single-degree-of-freedom rotating pair is replaced by a four-bar mechanism, which improves the bionic performance of the knee joint. Combining the feature description and the spatial planning algorithm model, an error compensation method based on iterative least square method is adopted to identify geometric parameters. The feature identification model of robot moving path planning is constructed, and the adaptive strong coupling tracking identification and path planning of robot moving path are realized through feature description and spatial distance error identification results. The simulation test results show that the cooperative positioning error is reduced and the torque error is compensated in real time by using this method to plan the movement path of the wearable lower limb exoskeleton robot, which makes the robot obtain better movement planning effect and enhance the stability of the mechanism.

Keywords—Feature description; wearable lower limb exoskeleton robot; motion path planning; least square identification; geometric parameter

I. INTRODUCTION

With the increasing types of robots and the expanding application fields of robots, the application of robots in rehabilitation training of patients with limb injuries has become an important direction of robot design and research. Wearable lower extremity exoskeleton robot is a training device designed for the disabled or powerless. The wearable lower extremity exoskeleton robot is worn on the lower limbs of patients, and the auxiliary parameter identification of multi-dimensional sensors is used as input, and the robot's movement planning design is realized through the robot control system and path planning system, which makes the wearable lower extremity exoskeleton convenient and comfortable to wear, safe and reliable to use, and fast and accurate to respond. Therefore, this paper studies the path planning method of wearable lower limb exoskeleton robot. Through path planning and intelligent

control system design, combined with power-assisted training design, the fitness level of robot under different wearing frequencies and training intensity is improved [1].

In the planning and design of the movement path of the wearable lower extremity exoskeleton robot, it is necessary to dynamically plan and design the movement path in combination with the user's power training needs and the wearer's injury degree. In the traditional methods, the movement path planning and design methods of the wearable lower extremity exoskeleton robot mainly include fuzzy PID control method, variable structure PID control method and inversion control method, etc. [2,3], and a distributed feature sampling model of the movement path of the wearable lower extremity exoskeleton robot is established. Combining spatial path parameter identification and inverse parameter control, the dynamic spatial fusion processing is carried out for patients with different degrees in the process of power-assisted training, and the movement path planning and design of wearable lower extremity exoskeleton robot is realized by using error compensation control algorithm and SLAM algorithm. In reference [4], a zero-force control method of 6-RUS parallel robot based on generalized coordinate form dynamics is proposed, and the influence of mechanism noise on torque data is analyzed. The global area method is used to obtain the actual output torque of the motor at a certain position in the workspace, so as to realize zero-force control and spatial path planning and design of the robot. However, the torque measurement accuracy of this method for robot moving path planning is not high. In reference [5], the configuration, motion mechanism and modeling control model of amphibious bionic robot are analyzed. According to the structural types of amphibious robots, amphibious robots are divided into leg propulsion, wheel-leg/fin composite propulsion, snake propulsion and other methods, and path planning and design are realized through parameter identification of multi-environment motion model, but this method has poor anti-interference and weak spatial recognition ability. Research [6] proposes the establishment of a mathematical model for robots, the construction of a motion situational awareness map, the establishment of an improved artificial potential field, the establishment of a repulsive potential function and priority model between robots, and the application of PID adaptive tracking algorithm. Study [7] proposes the use of adaptive RBFNN algorithm for disturbance estimation and compensation, and the use of nonlinear state error feedback control to achieve attitude tracking of rotor flying multi joint robotic arms, Has strong robustness and fast response ability.

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Aiming at the above problems, this paper puts forward a movement path planning model of wearable lower extremity exoskeleton robot based on feature description.

1) Different wearing frequencies and training intensities are taken as feature description objects, and the natural walking gait of the wearer is taken as constraint feature quantity and control object model, and a four-bar mechanism is adopted to replace the traditional single-degree-of-freedom rotating pair, thus improving the bionic performance of the knee joint.

2) Combining the feature description and the spatial planning algorithm model, the feature identification model of robot moving path planning is constructed by using the error compensation method based on iterative least square method, and the adaptive strong coupling tracking identification and path planning of robot moving path are realized through the results of feature description and spatial distance error identification.

3) The experimental test shows the superior performance of this method in improving the moving path planning ability of wearable lower limb exoskeleton robot.

This method can more accurately predict users' motion intentions and generate motion paths that better meet user needs by analyzing and modeling human motion features. Thus providing more precise and coordinated motion assistance, improving motion performance.

II. STRUCTURE MODEL AND DESIGN PRINCIPLE OF WEARABLE LOWER LIMB EXOSKELETON ROBOT

Based on the principle of ergonomics, a wearable exoskeleton robot for the disabled or powerless lower limbs is designed. The hip joint, knee joint and leg bar are designed respectively [6]. Firstly, at the left and right hip joints, the parallel mechanism is used to realize the power-assisted movement of the joint center. Then, the traditional single-degree-of-freedom rotating pair is replaced by a four-bar mechanism to realize the bending action of the knee joint. Then, the leg bar is designed according to the human body configuration. Finally, the ankle joint is designed by belt drive.

Among them, the hip joint is composed of Hooke's articulated U-pair, movable P-pair, Hooke's articulated U-pair, fixed platform connecting leg bars, and movable platform tied to the waist; The knee joint is composed of a four-bar linkage formed by articulation, a linear driving electric cylinder and a fixed part of the electric cylinder.

As shown in Fig. 1, the robot wearing the lower limb exoskeleton is composed of a hip joint A, a knee joint B, an ankle joint C, a leg bar D and an inner strap E which are connected by bolts in turn. Among them, as shown in the figure, the leg bar imitates the human body structure, and there is a certain angle between the thigh and the calf on the vertical plane, which makes the structure more suitable for the human lower limbs [7].

Fig. 2 is a schematic diagram of the hip joint structure, and the hip joint is assisted by a parallel mechanism. Among them, the parallel mechanism is composed of Hooke's articulated U-

pair A1, moving P-pair A2, Hooke's articulated U-pair A3, fixed platform A4 connecting leg bars and moving platform A5 tied to waist. The parallel mechanism can achieve three degrees of freedom of hip joint ergonomically required, namely, forward and backward swing (thigh flexion/extension), lateral swing (abduction/adduction) and torsion (external rotation/internal rotation), which is consistent with the freedom of motion required by human hip joint and ensures human comfort [8].

Fig. 3 is a schematic diagram of the structure of the knee joint, which realizes the bending motion of the knee through a four-bar linkage mechanism. Specifically, it consists of a hinged four-bar mechanism B1, a linear driving electric cylinder B2 and an electric cylinder fixing piece B3. Compared with the single-degree-of-freedom rotation, the instantaneous center trajectory of the four-bar mechanism is closer to the trajectory of the human knee joint, thus achieving the goal of better coordination between the exoskeleton and the human body [9].

Fig. 4 is a schematic diagram of the ankle joint structure. As shown in the figure, the ankle joint is composed of an upper joint fixing piece C1, a rotating pair end cover C2 and a rotating pair C3. When the human body walks, it can drive the rotating pair to rotate, improving the comfort experience.

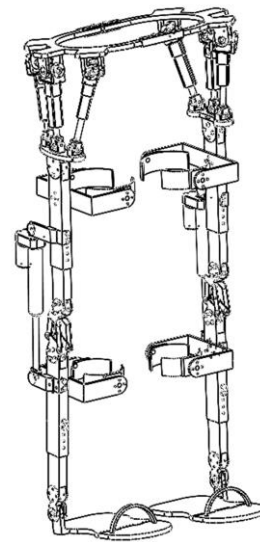


Fig. 1. Structure diagram of robot wearing lower limb exoskeleton.

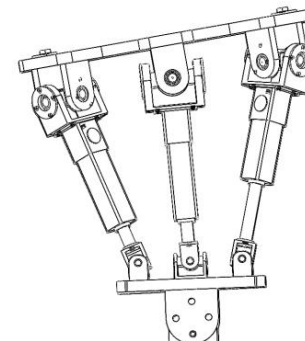


Fig. 2. Schematic diagram of hip joint structure.

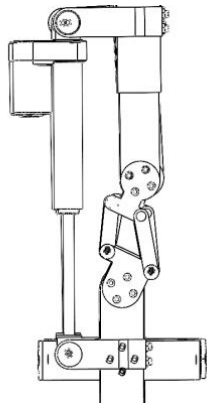


Fig. 3. Schematic diagram of knee joint structure.

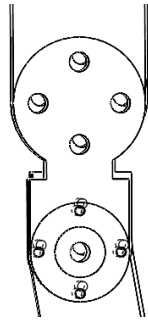


Fig. 4. Schematic diagram of ankle joint structure.

Advantages of wearing lower limb exoskeleton robot:

- 1) It is suitable for adjusting the length of lower limbs of people of different ages and heights, and it is convenient for wearers of different heights to perform various operations [10].
- 2) The left and right hip joints are designed in a parallel structure symmetrical about the central axis, and the movement center of the exoskeleton and the center of the human hip joint are more fitted, which ensures that the movement center of the wearable robot falls on the center of the hip joint, thus ensuring the fit between the wearable robot and the human body, being more bionic and enhancing the comfort of users.
- 3) The knee joint adopts a four-bar mechanism to replace the traditional single-degree-of-freedom rotating pair, which improves the bionic performance of the knee joint. Combining with ergonomics, the thigh in the standing state is set to be vertical to the horizontal plane, and there is a certain angle between the calf and the thigh, so that the center of gravity of the human body falls inside the ankle joint and the sole support to enhance the stability of the mechanism.

Both the upper and lower leg connecting rod and the lumbar support structure are telescopic, as shown in Fig. 5 and Fig. 6, that is, the upper and lower leg connecting rod and the lumbar support structure are designed into two sections with adjusting threaded holes, so as to improve the body compatibility with robot wearers, adapt to the bodies of different patients and improve the comfort.

In the design process, according to the bionic design method, the hip joint, knee joint and ankle joint of exoskeleton are designed, in which the hip joint adopts parallel mechanism and the knee joint adopts four-bar mechanism closer to the knee joint instead of the traditional rotating pair. The leg bar part adopts an adjustable two-bar structure, which is convenient for different people to wear.

III. CONSTRAINT PARAMETERS AND CONTROL OBJECTS OF ROBOT MOVING PATH PLANNING

A. Constrained Parameter Model

In order to realize the movement path planning of the wearable lower extremity exoskeleton robot based on feature description, inspired by the musculoskeletal system of human leg [11], firstly, the collection model of the sensitive parameters of the trajectory tracking deviation of the skeletal robot is established, and the Snelson X-shaped mechanism is improved. According to the biological simplified model and deformation feature analysis, the internal biomechanics and motion mechanism of the human leg are analyzed, and the distribution of the sensitive parameters of the timing deviation of the wearable lower extremity exoskeleton robot is obtained as follows:

$$F = \frac{\int_0^{L_z} T_C(x) dx}{L_z} + \frac{M \cos \alpha}{4\pi\mu_0 R^5} [2(2h)^2 - a^2] \quad (1)$$

Where, $\int_0^{L_z} T_C(x) dx$ represents the number of internal biological spine or trunk joints of human legs, L_z represents the geometric shape parameters of bone and femoral condyle surfaces, M represents the dynamic characteristic components of muscle and bone in the equivalent mapping model, and h represents the flexible dynamic parameters imitating human muscle tissue. Based on the energy loss analysis, the dynamic characteristic parameters of redundant degrees of freedom of tensegrity structure are obtained as follows:

$$P = P_{cu} + P_h + P_e = \sum_{n=m}^{N-1} \left\{ \left[e^f_{m-1}(n) \right]^2 + \left[e^b_{m-1}(n-1) \right]^2 \right\} \quad (2)$$

In the above formula, P_{cu} is the inertia loss of the wearable lower limb exoskeleton robot around each axis of the body coordinate system, P_h is the force density distribution matrix, and P_b is the component group of the axial force f of the node P in the X and Z directions. Assuming that the unit size of the

tensegrity mechanism is μ_1 , it can be analyzed and identified according to the diagonal matrix composed of axial stiffness deformation, so as to realize the analysis of the changing posture and movement position [12].

B. Control Object Model

Taking the wearer's natural walking gait as the constraint feature quantity and the control object model, the spatial planning and design of the hip joint, knee joint and ankle joint of the exoskeleton are adopted, and the steady-state control model of the characteristics of the Snelson X tensegrity structure itself is obtained as follows:

$$S = K(t) + \sum_{n=m}^{N-1} \left[e^b_{m-1} (n-1) \right]^2 \quad (3)$$

Where, e^b_{m-1} is the complementary sequence of the cooperative positioning errors of the two legs, and $K(t)$ is the measured distance between the end effectors of the two legs. Based on the identified geometric parameters, the behavior conditions of the two legs are analyzed, and when $F^T F \leq I$ is met. Calculate the measured distance of the robot end when it is configured as i and k , and get the quantitative parameters of the trajectory feature distribution of the wearable lower limb exoskeleton robot as follows:

$$Y_\phi = \frac{\omega \dot{M}}{4\pi R^2} + \left[e^f_{m-1}(n) e^b_{m-1}(n-1) \right] \quad (4)$$

Where, R is the characteristic value of the rotation period, based on the kinematic characteristics of nonlinear feedback control, the controlled object model is constructed based on the description and analysis of joint offset, connecting rod length and connecting rod torsion characteristics, and the geometric stiffness equation of the wearable lower limb exoskeleton mechanism is obtained by the method of modifying the geometric stiffness matrix of the mechanism:

$$u(k) = Kx(k - (\tau_{sc} + \tau_{ca})) = Kx(k - \tau_k) \quad (5)$$

According to the kinematics model of the robot from the measuring coordinate system to the end tool coordinate system, the actual arrival position of the end effector is inconsistent with the calculated position of the theoretical model. The geometric parameters are identified and analyzed, and the error compensation terms SA of the left leg and the right leg of the two-legged system are obtained by using the combined control of Coriolis force and centrifugal force $w^{(k)} \in L_2(0, \infty)$. When $\|z(k)\|_2 \leq \gamma \|w^{(k)}\|_2$ is met, according to the dynamic characteristics analysis of joint offset, connecting rod length and connecting rod torsion, the spatial planning function of kinematic model of end tool coordinate system is obtained as follows:

$$V_k = x^T(k) P x(k) + \sum_{i=k-\tau_k}^{k-1} x^T(i) K^T R K x(i) \quad (6)$$

Where P , R are displacement vectors of geometric parameter errors of the robot. For the dynamic modeling of the wearable lower limb exoskeleton robot, the vector between the

origin points of the end tool coordinate system is introduced, and the gradient gain function is obtained according to the detection result of the transformation matrix of the basic coordinate system of the biped robot:

$$\begin{aligned} \Delta V_k &= Vx(k+1) - Vx(k) \\ &= x^T(k+1) P x(k+1) - x^T(k) P \\ &\quad - K^T R K x(k) - x^T(k - \tau_k) K^T R K x(k - \tau_k) \end{aligned} \quad (7)$$

While $w^{(k)}=0$, the position detection model of the ends of legs in the measurement coordinate system is constructed, and the spatial planning and design of the robot's moving path is realized according to the position distribution [13].

IV. OPTIMIZATION OF MOBILE PATH PLANNING ALGORITHM FOR WEARABLE LOWER LIMB EXOSKELETON ROBOT

A. Feature Description and Spatial Planning Algorithm

The hip joint, knee joint and ankle joint of exoskeleton are planned and designed in space, and the four-bar mechanism is used to replace the traditional single-degree-of-freedom rotating pair, which improves the bionic performance of the knee joint [14]. The gradient vector of cooperative positioning between the theoretical end distance and the real end distance meets the following requirements:

$$\Delta V_k = \Phi_1 \Pi_1 \Phi_1^T < 0 \quad (8)$$

Taking the centroid parameters of the wearable lower limb exoskeleton robot as the constraint object, through error compensation and feature description, the distribution function of the end position in the ontology-based coordinate system is measured as follows:

$$F(x) = \sum_{q=1}^Q e_q^T e_q = \sum_{q=1}^Q \sum_{k=1}^m e_{kq}^2 = \sum_{i=1}^N v_i^2 \quad (9)$$

Where, eq is the matching sample set of the best trajectory path of the wearable lower limb exoskeleton robot. Through the calibration of geometric error and non-geometric error, the distribution of transformation parameters of the two-leg base coordinate system is obtained as follows:

$$x^T = [w_{11}, \dots, w_m, z_{11}, \dots, z_{m}] \quad (10)$$

Where, $w_{11}, \dots, w_m, z_{11}, \dots, z_m$ are the inertia weights, after geometric and non-geometric error compensation, the control function of feature description and spatial planning optimization is obtained as follows:

$$k_m = R / \rho_{m-1} = \frac{P_L}{P_E} = \left\{ \left[e^f_{m-1}(n) \right]^2 + \left[e^b_{m-1}(n-1) \right]^2 \right\} \quad (11)$$

Where, ρ_{m-1} is the tracking expected displacement vector that oscillates during the identification process, P_L is the change rate of the position distribution of the laser tracker, and

P_E is the joint angle variable of the left leg in the right leg base coordinate system, thus the formula for the tracking step size distribution of the end position trajectory is obtained as follows:

$$C(t) = V_0^2 \cdot G_x = \sigma_{wp}^2 \left(\frac{N+P+1}{N-P-1} \right) \quad (12)$$

Wherein, G_x is the system gain of the end position and σ_{wp}^2 is the transformation parameter of the base coordinate system. The dynamic analysis model of the movement path planning of the wearable lower limb exoskeleton robot is analyzed to realize the dynamic planning and design of the movement path of the skeletal robot [15].

B. Adaptive Strong Coupling Tracking and Identification of Robot Moving Path

The four-bar mechanism is used to replace the traditional single-degree-of-freedom rotating pair, which improves the bionic performance of the knee joint. The proposed four bar mechanism has significant advantages in improving the bionic performance of the knee joint compared to traditional rotating pairs. It can better simulate the complex motion of the human knee joint and provide torque output that conforms to the physiological characteristics of the human body through improvements in multi degree of freedom control, torque distribution, stability, and controllability. In addition, the four bar mechanism can also save energy, improve energy utilization efficiency, extend battery life, or reduce external energy consumption. Overall, the introduction of a four bar mechanism can significantly improve the bionic performance of the knee joint, making it closer to the motion characteristics and functions of the human knee joint.

Combining the feature description and the spatial planning algorithm model, the control model of the dynamic planning of the left leg in the right leg base coordinate system is obtained by using the error compensation method based on the iterative least square method to identify geometric parameters and the optimization constraint method.

$$\dot{\sigma}_i = \begin{cases} \mu \sin \frac{\pi e}{2\mu}, & |e_i| < \mu \\ \mu, & |e_i| \geq \mu \\ -\mu, & |e_i| \leq -\mu \end{cases} \quad (\mu > 0) \quad (13)$$

Where, μ is the sliding mode switching gain and e_i is the trajectory deviation error, trajectory tracking and spatial planning are carried out according to the correlation between the steady-state disturbance $w^{(k)}$ of the step tracking of the wearable lower extremity exoskeleton robot and the acceleration measurement matrix $u_i^{(k)}$, and the trajectory distribution spatial parameters of the wearable lower extremity exoskeleton robot are obtained based on geometric error and non-geometric error calibration, and the parameter

identification model of the spatial positioning and perception of the mobile robot is described as follows:

$$H_0 = \sqrt{E}KR'(t) + R(t) - \left(\frac{P_e + P_h}{\omega_r} \right) \frac{M}{4\pi\mu_0 R^3} \sqrt{1 + 3\cos^2 \theta} \quad (14)$$

$$T(\alpha) = T + Y(r) - (P_w + P_b) / \omega_r \quad (15)$$

Wherein, μ_0 is the dynamic distribution parameter with the smallest linearization error of the system, M is the fuzzy distribution matrix in the robot base coordinate system, P_e is the error of identifying geometric parameters, P_h is the base coordinate system from the right leg to the left leg, $R(t)$ is the coordinate matching point of each mechanism node, $R'(t)$ is the parameter matrix of the mechanism unit node. The error compensation method based on iterative least square method is used to identify geometric parameters, and the feature identification model of robot moving path planning is constructed. The adaptive strong coupling tracking identification and path planning of robot moving path are realized through feature description and spatial distance error identification results [16].

V. EXPERIMENTAL TEST

In this simulation experiment, we choose ROS as the simulation environment, and use SolidWorks modeling to create a lower limb Exoskeleton robot model. Obtain joint angle data as motion features through sensors and input it into a feature based path planning algorithm. In the experimental scenario, we simulated walking tasks and set different environmental conditions, with a ground slope range of [0,10] and 10 obstacles randomly distributed in the environment. The robot can complete the movement and reset of hip joint and knee joint with a single motor drive, and the input pressure reaches the maximum at 100N, and the dynamic error difference of trajectory tracking is set to 0.14mm. When the robot stands and locks, the deviation of the constraint point is 12.7%, the offset length is 1.355mm, the torsion angle of the connecting rod is 1.570rad, and the length of the connecting rod is 3.125. A four-bar mechanism is adopted to replace the traditional single-degree-of-freedom rotating pair, and the maximum/average position error of the robot is 0.2814mm/0.1431mm, and the average inverse kinematics calculation time of the robot's hip joint driven by DC motor is 0.01134ms, which is the longest for the robot. The setting parameters are shown in Table I.

According to the above parameter setting, given that the time of lower limb flexion is 0.064s, the support ability of the lower limb in the standing state is tested, and according to the statistical analysis results of mechanical characteristic parameters, the wearable lower limb exoskeleton robot is realized, and the detection results of robot movement path tracking parameters are shown in Fig. 5.

TABLE I. DH PARAMETER DISTRIBUTION

Joint node	Joint angle /rad	Offset length /mm	Connecting rod torsion angle a_i /rad
1	0.921	76.456	5.626
2	1.059	79.955	6.656
3	0.598	83.033	3.666
4	1.245	76.936	8.900
5	1.225	80.504	8.371
6	1.627	80.435	9.400
7	0.627	81.337	8.469
8	1.931	79.710	7.665

By analyzing Fig. 5, it is known that this method can accurately detect the moving path of the robot, and the trajectory tracking and recognition ability is good, and the legged robot always maintains a stable locking state during the process of increasing the load. The convergence curve of the test robot's moving path tracking is shown in Fig. 6.

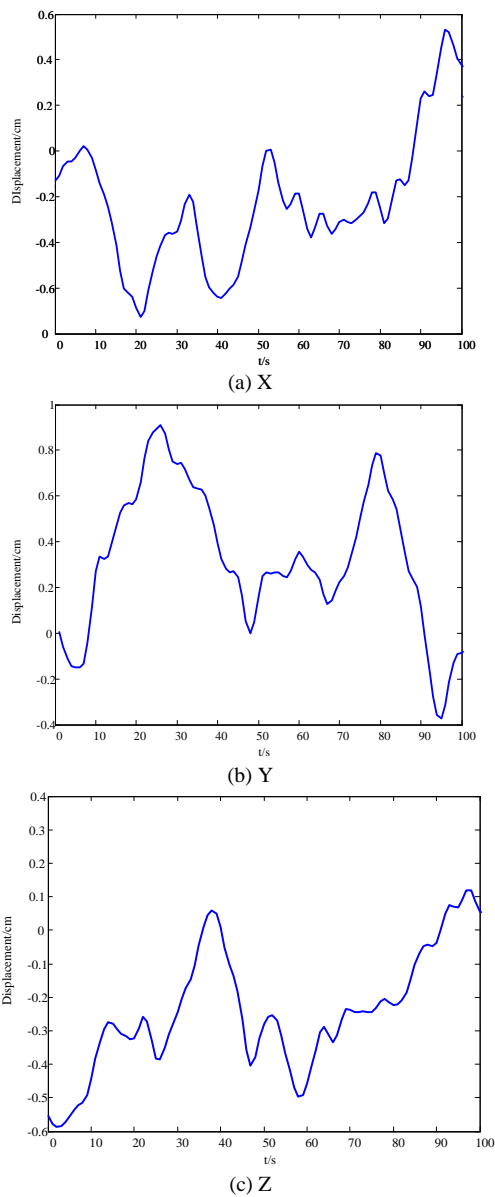


Fig. 5. Detection of robot moving path tracking parameters.

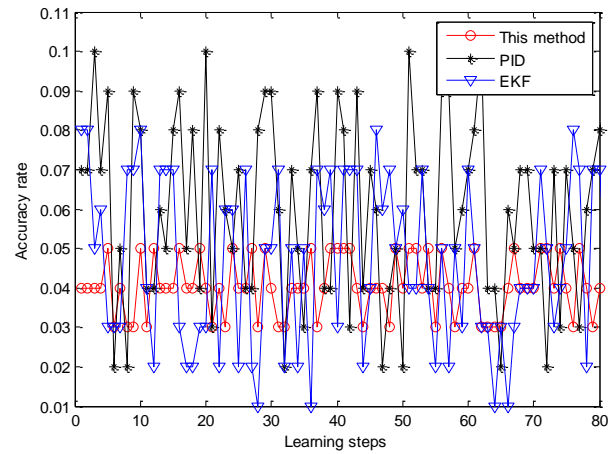


Fig. 6. Convergence curve of robot trajectory tracking.

By analyzing Fig. 6, we know that the method in this paper has a good convergence when planning and tracking the movement path of the wearable lower extremity exoskeleton robot, while the traditional PID control method has a large oscillation and the convergence error of EKF control method is high. The tracking error of the movement path of the wearable lower extremity exoskeleton robot is tested, as shown in Table II. By analyzing the results in Table II, we know that the method in this paper has a good adaptability and strong oscillation suppression ability, which improves the stability and robustness of the movement planning of the wearable lower extremity exoskeleton robot.

TABLE II. COMPARISON OF TRAJECTORY TRACKING ERRORS

Iterations	This method	PID	EKF	Integral control
100	0.041	0.135	0.403	0.189
200	0.018	0.084	0.132	0.151
300	0.006	0.057	0.136	0.177
400	0.000	0.023	0.110	0.074

Through the analysis of the comprehensive experimental results, the method proposed in this paper shows accuracy and stability in the path planning of the wearable lower limb Exoskeleton robot. The experimental results show that this method can accurately detect the motion path of the robot and has strong trajectory tracking and recognition capabilities. Even with increased load, the legged robot can still maintain a stable locking state. In addition, the method shows good convergence and low tracking error when planning and tracking the path of the wearable lower limb Exoskeleton robot.

Through experimental verification, we found that our method has excellent performance in path planning. It can accurately identify the user's motion intention and generate motion paths that match the user's needs. At the same time, this method can also adaptively adjust according to environmental changes and individual differences of users to provide more comfortable and efficient motion assistance. In addition, the method shows stability and accuracy in the tracking process, and can accurately track the user's trajectory, so that the Exoskeleton robot can effectively work with the user.

However, it should be noted that although the method presented in this paper has shown good performance in experiments, there are still some limitations. For example, the accuracy of feature extraction and description may be influenced by factors such as sensor accuracy, noise, and interference. In addition, further research is needed to consider individual differences and adaptability. Therefore, before applying this method to practical scenarios, it needs to be further validated and improved.

VI. CONCLUSIONS

In order to improve the environmental adaptability of the robot and better meet the usage habits of patients, it is necessary to plan and design the movement path. A movement path planning model of the wearable lower limb exoskeleton robot based on feature description is proposed, with different wearing frequencies and training intensities as the feature description objects, and the wearer's natural walking gait as the constraint feature quantity and control object model, and the hip joint, knee joint and ankle joint of the exoskeleton are used for spatial planning and design. A four-bar mechanism is used to replace the traditional single-degree-of-freedom rotating pair, which improves the bionic performance of the knee joint. Combining the feature description and the spatial planning algorithm model, a feature identification model of robot movement path planning is constructed by using the error compensation method based on iterative least square method, and the adaptive strong coupling tracking identification and path planning of robot movement path are realized through the results of feature description and spatial distance error identification. The simulation test results show that this method can reduce the cooperative positioning error and compensate the torque error in real time, which makes the robot obtain better movement planning effect and enhance the stability of the mechanism. The trajectory tracking of the wearable lower extremity exoskeleton robot has good adaptability and strong oscillation suppression ability. There may be differences in the motion characteristics and needs of each user. The current research mainly focuses on average feature descriptions and models, and the consideration of individual differences is not sufficient. Therefore, in practical applications, further research is needed on how to incorporate individual differences and adaptability into the path planning process.

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