Slope Gait Control Method for Biped Robot Based on Adaptive Neural Network

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Abstract: In order to solve the problem of slow convergence and poor real-time control of current biped robot slope gait control methods, an adaptive neural network based slope gait control method for biped robot is proposed. Using D-H representation, the kinematics model of biped robot is established, and the adaptive neural network technology is used to import the kinematics model of biped robot to predict the gait of robot locomotion. By using the judging factor, the lag adjustment mechanism of the rhythm generating layer is determined, the phase gait is corrected, and the Van der is used. Pol vibrator is used to alleviate the phase mutation after the phase reset, and the phase mutation in the phase correction is dispersed in the subsequent motion vibration to realize the slope gait control of the biped robot. The experimental results show that the gait control method designed in this paper has good real-time performance and can effectively speed up the convergence speed.

Keywords: adaptive neural network; gait control; biped robot; convergence rate;

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Introduction

Biped robot is one of the humanoid mobile robots, which can run in the complex terrain environment such as streets, stairs, ruins and so on. It is widely used in rescue, medical, exploration, service and other fields[1]. Because of its simple structure, flexible gait and low energy consumption, biped robot has been widely studied. The biped robot can walk along the slope only by its own gravity and inertia through the dynamic characteristics.

In the field of robot, biped robot has low requirements for road surface and good walking adaptability, which has become a hot spot in the field of robot research [2]. However, biped robot is prone to lead or lag when walking, so it is necessary to control its walking gait. In foreign research, firstly, through the in-depth study on the influence of fixed parameters and different slope angles on the robot, the change law of chaotic gait is obtained, and the delayed feedback control is proposed, but only the single cycle gait of the robot can be controlled [3]. On this basis, Chinese scholars put forward a comprehensive gait control method using Q-learning underdrive method. Although the overall gait control is realized, the calculation of this method is relatively complex and the data convergence speed is too slow, which still needs further improvement [4].In order to solve the above problems, a biped robot slope gait control method based on adaptive neural network is proposed. Through the adaptive neural network technology, the kinematics model of the biped robot is introduced to predict the robot's gait. The slope gait control of the biped robot is realized, the convergence speed is accelerated and the real-time control is improved.

1 A slope gait control method for biped robot based on adaptive neural network

1.1 Establishment of the kinematics model of biped robot

Before gait control of the biped robot, the kinematics model of the biped robot should be established to provide motion calculation support [5]. As the biped robot is moving forward, its supporting foot contacts the ground and is in a fixed state. Therefore, this paper takes the center point of the supporting foot of the biped robot as the origin O of the coordinate system, establishes the coordinate system of ankle joint and hip joint according to the origin, and establishes the kinematics model of the biped robot by using D-H representation. The local coordinate system of its connecting rod is as Fig. 1,

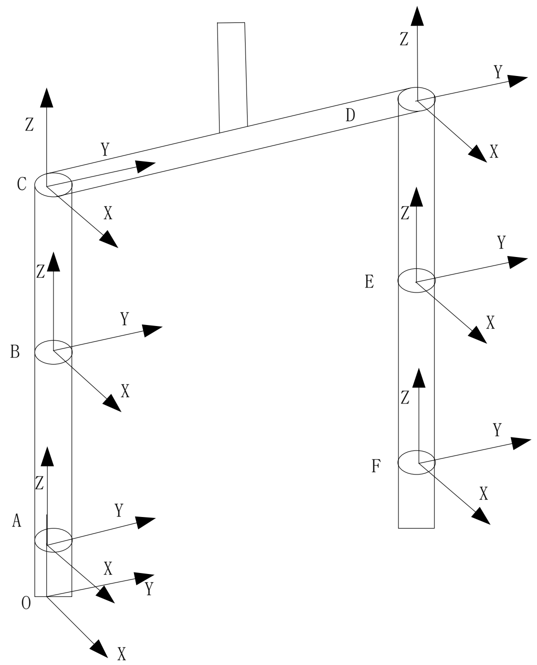

Fig. 1 Local coordinate system of biped robot connecting rod

In Fig. 1, the x axis direction is taken as the forward direction of the robot. The z axis direction is above. The y axis is determined according to the x axis direction. Taking the right ankle joint as the center point, the local coordinate system A is established. According to this method and the D-H method, a coordinate system $n+1$ is established for the robot with joints with the number of n. In this paper, In this paper, the basic coordinate system is defined as O_0, and the joint i coordinate system is set as O_i. In this paper, by using the theory of homogeneous change matrix[6], the homogeneous matrix of adjacent coordinate system is obtained, that is ${}^{i-1}\boldsymbol{T}_i$. Based on this, the transformation matrix ${}^{0}\boldsymbol{T}_i$ is obtained. The formula is as follows,

$$ {}^{0}\boldsymbol{T}_i = {}^{0}T_1 {}^{1}T_2 \dots {}^{i-1}\boldsymbol{T}_i = \begin{bmatrix} {}^{0}\boldsymbol{R}_i & {}^{0}P_i \\ 0 & 1 \end{bmatrix} \tag{1} $$

In formula (1), ${}^{0}\boldsymbol{R}_i$ and ${}^{0}P_i$ represent rotation matrix and position vector in coordinate system. After obtaining ${}^{0}\boldsymbol{T}_i$, the coordinate representation of the member in the coordinate system can be obtained. In this paper, the forward direction of the rotation axis is defined as clockwise direction. The x axis rotation angle of the right ankle joint is set to $-\theta_0$ and the y axis direction is set to θ_2, then the rotation matrix in the coordinate system A can be obtained as $\boldsymbol{R}_x(-\theta_0)\boldsymbol{R}_y(\theta_2)$. The coordinates of the origin O in the coordinate system A can be expressed as $\begin{bmatrix} 0 & 0 & L_0 \end{bmatrix}^T$. The homogeneous matrix between the coordinate system A and the coordinate system O can be obtained by calculation,

$$ \bar{\boldsymbol{G}}_{AB} = \begin{bmatrix} \cos\theta_4 & 0 & \sin\theta_4 & 0 \\ 0 & 1 & 0 & 0 \\ \sin\theta_4 & 0 & \cos\theta_4 & L_1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{2} $$

According to the above method, the homogeneous matrix between all other coordinate systems and the coordinate system O are obtained, and the motion model of the biped robot is established.

1.2 Gait prediction of robot based on adaptive neural network

As a more complex dynamic model, biped robot has a variety of motion forms. Before the robot is controlled, it is necessary to predict the robot's gait[7]. In this paper, considering that the adaptive neural network has better learning speed and generalization ability, it can be used as real-time prediction of biped robot. Through the robot motion model established above, the adaptive neural network can be used for calculation. In this paper, $x_1, x_2, \dots x_r$ is set as the input variable of neural network.

$y_1, y_2, ..., y_m$ is set as the output variable. MF_{ij} is set as the j membership function of the i input variable. The j fuzzy rule in the membership function is set to be R_j, in which the j normalized node is set to be N_j. u represents the total number of rules of the neural network. The membership function layer in the network is expressed in the form of Gaussian function as follows,

$$u_{ij}(x_i) = \exp\left[-\frac{(x_i - c_{ij})}{\sigma_{ij}^2}\right] i = 1, 2, ..., r \qquad j = 1, 2, ..., u \tag{3}$$

In formula (3), u_{ij} is set as a membership function of x_i. c_{ij} and σ_{ij} represent the center and width of Gaussian function. In the neural network of this paper, each node is regarded as a RBF unit and represents a possible fuzzy rule. In the prediction, the data can be normalized through the normalization layer. The node in the normalization layer is set to be N, and outputs N_j through the node pair j as follows,

$$\varphi_j = \frac{\phi_i}{\sum_{k=1}^{u} \phi_k} j = 1, 2, ..., u \tag{4}$$

The output results obtained by the fuzzy output layer are as follows,

$$y_t(X) = \sum_{k=1}^{u} \omega_{kt} \cdot \varphi_k \qquad t = 1, 2, ..., m \tag{5}$$

In formula (5), y_t is the output of the variable in the neural network. ω_{kt} represents the connection weight of the fuzzy rule in the t output. At the same time, because the structure of the adaptive neural network does not need to be set in advance, and the network itself will be gradually improved and learned. At the same time, according to the changes of the network, the network structure and content parameters are adjusted in real time, including the generation of fuzzy rules and the determination of weights[8]. In the process of confirmation, for the i prediction data (X_i, t_i), X_i represents the input data of the neural network and t_i represents the expected output of the neural network. The output y_i in the neural network structure is obtained according to formula (5), and the error $\|e_i\| = \|t_i - y_i\|$ is defined. In the training process, it is necessary to describe the admissible boundary of the neural network, calculate the input value X_i of the i observation data (X_i, t_i) and calculate the distance $d_i(j)$ of the center C_j in the existing RBF unit.

$$d_i(j) = \left\| X_i - C_j \right\| \; j = 1, 2, \ldots, u \qquad (6)$$

In this formula, u represents the number of existing fuzzy rules, and according to the calculation results of formula (6), the minimum distance $d_{\min}$ is obtained,

$$d_{\min} = \arg\min\left(d_i(j)\right) \qquad (7)$$

In the comparison of $d_{\min}$, it is necessary to set the effective radius $d_{\min}$ of the admissible boundary in the network in advance. When $d_{\min} > k_d$ in the network, it means that the Gaussian unit in the network can not cover the current observation data. It is necessary to add fuzzy rules to the network, so that the data can be fully covered by the Gaussian unit. When $d_{\min} \le k_d$, it shows that there can be new observation data in the Gaussian unit, and no rules to be added.

1.3 Slope gait correction of biped robot

By using the gait prediction of the biped robot on the slope, the phase gait is corrected[9]. Firstly, a rhythm assisted oscillator is established to mitigate the phase mutation caused by phase reproduction, and the phase mutation during phase correction is dispersed in the subsequent motion vibration. In this paper, the Van der pol oscillator of the rhythmic oscillator is used as the auxiliary oscillator.

$$\begin{cases} \dot{c}_0 = e_0 + k\left(c - c_0\right) \\ \dot{e}_0 = 0.1 \times \left(1 - 4c_0^2\right)e_0 - \omega_0^2 c_0 + k\left(e - e_0\right) \end{cases} \qquad (8)$$

In formula (8), both c and e represent the output of the rhythmic oscillator. c_0 and e_0 are coupling coefficients. k is the corresponding rate factor. For the robot's touchdown and lift off, the same adjustment mechanism is used. By resetting the rhythm signal, the movement rhythm of the biped robot can be synchronized with the body motion state of the robot. In the period, the phase of rhythm signal changes from 0 to 2π, and the process of swing phase to support phase also occurs at $\pi/2$. The transition of support phase occurs at $3\pi/2$. If $\pi/2$ leaves before touchdown, it is gait ahead, and then the discriminant factor of the walking condition of the biped robot can be obtained.

$$\alpha_a = \begin{cases} 1, 0 \le \varphi < \dfrac{\pi}{2} \\ 0, other \end{cases} \qquad \alpha_b = \begin{cases} 1, \pi \le \varphi < \dfrac{3\pi}{2} \\ 0, other \end{cases} \qquad (9)$$

In formula (9), α_a represents the advance adjustment phase discriminant factor for robot touchdown. α_b represents the phase identification factor for robot's lift off ahead adjustment. φ represents the phase of the robot's rhythmic signal. In order to ensure the judgement of advance adjustment, the direction of the discriminant factor in the touchdown state should be adjusted in verse direction.

$$\xi_a = \begin{cases} 1, F \geq F_0 \\ 0, F < F_0 \end{cases} \qquad \xi_b = \begin{cases} 0, F \geq F_0 \\ 1, F < F_0 \end{cases} \tag{10}$$

In formula (10), ξ_a represents the touchdown discrimination factor of the robot. ξ_b represents the lift off discrimination factor of the robot. F represents the plantar force sensor value. F_0 represents the plantar force threshold value of the robot. By using the discriminant factors mentioned above formula (9) and formula (10), the gait of the robot is adjusted ahead of schedule. The lag adjustment of robot is achieved by synchronizing the motion state and the rhythm signal when the rhythm signal stops oscillating. The swing phase of the robot occurs at $\pi/2$ during the transition of the supporting phase, and the supporting phase of the robot moves towards the swing phase occurs at $3\pi/2$. When the robot gait is predicted and the robot is found at $\pi/2$ and it has not touched the ground or not leaving the ground at $3\pi/2$, the later phase correction is carried out. The expression of lag phase determination factor is as follows,

$$\beta_a = \begin{cases} 1, \frac{\pi}{2} \leq \varphi < \frac{\pi}{2} + \square \\ 0, other \end{cases} \qquad \beta_b = \begin{cases} 1, \frac{3\pi}{2} \leq \varphi < \frac{3\pi}{2} + \square \\ 0, other \end{cases} \tag{11}$$

In formula (11), β_a represents the phase discrimination factor of the robot when it touches the ground. While β_b represents the phase discrimination factor when the robot leaves the ground. V represents the judgment margin. By using the determining factor[10], the lag adjustment mechanism of the rhythm generating layer can be determined. By adjusting the lag coefficient of the robot, the vibration speed and acceleration of the robot are set to 0, and the robot's rhythmic oscillator stops vibration. When the phase synchronization of the motion phase is synchronized, the starting vibration of the initial stop state is more stable, and the gait correction of the robot is completed, and the slope gait control of the biped robot is realized.

2 Simulation experiment analysis

In order to verify the effectiveness of the control method designed in this paper, the simulation experiment is carried out. Firstly, the slope is determined, and the inclination angle is $\gamma = 0.182$ .The initial gait of the biped robot is $\left[\theta_1, \bar{\theta}_1, \theta_2, \bar{\theta}_2\right] = \left[0.5942, -1.6833, -0.4979, 6.1781\right]$. The robot is in a hybrid gait. The gait control simulation is carried out by using the control method in this paper. In addition, in order to prove the real-time performance of the control method in this paper, the gait control methods in reference [1], reference [2] and reference [3] are used to compare the convergence time of gait control to judge the advantages and disadvantages.

2.1 Gait control results of biped robot

In step 11 of the simulation experiment, the predictive gait feedback is applied to the biped robot, and the initial value $K_{11} = \begin{bmatrix} 1.8 & 1.12 \\ -0.24 & -0.02 \end{bmatrix}$ of the feedback gain is obtained. At the same time, the adaptive iteration is carried out. The variation curve of hip joint angle of biped robot before gait control is as Fig. 2,

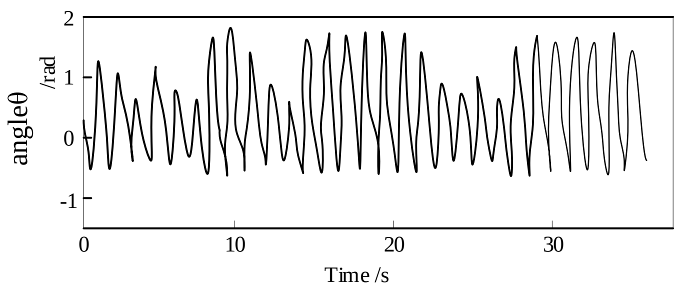

Fig. 2 Gait angle curve of biped robot

In Fig. 2, it can be seen that under the slope of simulation experiment, the biped robot is in chaotic gait. In the follow-up robot movement, after 35 s, the gait angle curve obtained is as Fig. 3,

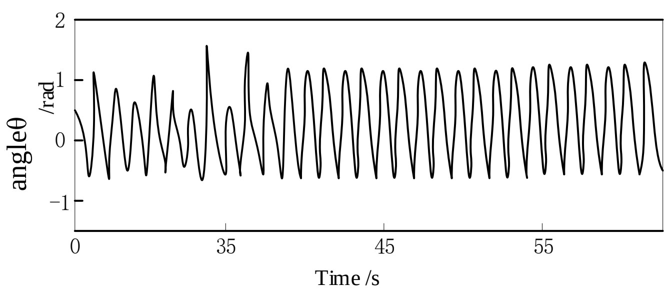

Fig. 3 Angle change curve of biped robot after gait control

In Fig. 3, it can be seen that the gait curve of the biped robot gradually tends to be stable after 35 s, and the gain oscillation of the controller also converges. It is proved that the convergence speed of the slope gait control method for biped robot designed in this paper is faster and feasible.

2.2 Control gait convergence time comparison

In the gait control of robot, the lower the pace convergence speed is, the better the real-time control ability of the control method is. In this experiment, on the basis of the above experiments, the gait control methods in references [1], [2] and [3] are selected for gait control simulation under the same conditions. The concept of gait convergence time is that the norm of the difference between the initial state of the biped robot and the fixed point is lower than the 10^{-3} time used. At the same time, in order to ensure the accuracy of the comparison results, the selection is made in different intervals of the initial state of the biped robot, $\theta 1 \in [0.56, 0.71]$, $\theta 2 \in [-1.42, -1.66]$, $\theta 3 \in [-0.4, -0.81]$, $\theta 4 \in [3.7, 6.4]$. 12 groups are selected to compare the convergence time, the accuracy of the experimental results is improved by increasing the number of experiments, and the gait convergence time of the biped robot on the slope is obtained as Table 1,

Table 1 Comparison of gait convergence time

Initial state of robot θ1	θ2	θ3	θ4	Convergence time of method 1 (ms)	Convergence time of method 2 (ms)	Convergence time of method 3 (ms)	Convergence time of method 4 (ms)
0.7053	-1.4382	-0.5231	3.9864	215	289	564	366
0.5927	-1.4355	-0.5886	5.1721	191	297	398	382
0.5877	-1.4681	-0.7562	4.6681	203	285	517	398
0.7021	-1.5274	-0.6155	4.1751	189	286	367	276
0.6517	-1.5933	-0.6871	5.2098	176	388	386	298
0.6984	-1.5241	-0.5542	6.1754	186	365	447	299
0.6058	-1.6248	-0.5961	5.9217	172	298	515	415
0.5934	-1.6534	-0.7874	4.9186	209	405	564	442
0.6219	-1.4893	-0.7124	5.3918	165	299	399	398
0.6848	-1.4436	-0.5961	6.2654	182	279	392	399
0.6645	-1.6421	-0.6148	5.9927	145	381	380	285
0.6872	-1.6128	-0.7988	6.1833	199	292	387	331

In Table 1, method 1 is the gait control method designed in this paper. Method 2 is the gait control method in reference [1]. Method 3 is the gait control method in reference [2]. Method 4 is the gait control method in reference [3]. In the 12 times convergence time, the average convergence time of method 1 is 186ms. The average convergence time of method 2 is 322ms. The average convergence time of method 3 is 443ms. The average convergence time of method 4 is 357ms. The convergence time of method 1 is lower than that of other slope gait control methods. It is proved that the slope gait control method of biped robot designed in this paper has better real-time performance. It has excellent performance and feasibility.

3 Conclusion

In this paper, the adaptive neural network is used to improve the gait control method of the robot. On the basis of realizing the gait control, the data convergence efficiency is improved and the real-time performance of the gait control is improved. However, the gait control method designed in this paper is put forward on the premise of determining the robot model, which can not control the object with uncertain model, so it needs further research and improvement.

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