Gait Tracking Control of Machine Leg Based on Damping Torque Feedback Control

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Keywords: Damping torque, kinematics model,robot leg, bionics, gait tracking control.

Abstract: The machine leg is affected by the damping of the joint part when walking in the bionic gait, which leads to the poor global stability. A gait tracking control method for machine legs based on damping torque feedback regulation is proposed. Kinematics analysis of the kinematics equation of the machine leg is constructed by three-axis coordinate system model. The adaptive optimization of the step sensing information of the robot leg with the parameters of the gait motion and the damping torque as the constraint index. An inverse stabilization control method is introduced to modify the error feedback of the gait tracking parameter of the machine leg. The feedback adjustment of damping torque is realized by combining the nonlinear adaptive inversion integral method, and the gait stability tracking control of the machine leg is realized. The simulation results show that using this method to track gait control of machine legs, the walking performance of machine legs is good, the tracking accuracy of attitude parameters is strong, and the attitude error is small.

1 INTRODUCTION

A bionic robot leg is a robot that walks by simulating human and animal walking, as an important application direction of AI robot, it has a very good application value in the field of artificial auxiliary operation, lower limb assisted rehabilitation, detection, tracking and recognition. The gait control of the bionic machine leg is the key to ensure the stable walking of the machine leg. The gait tracking control system of machine legs is a multivariable, nonlinear and non-stationary multivariable control system. It is necessary to control its robustness and improve the robustness and smoothness of bionic gait control. In order to improve the robustness of the bionic gait control and the stability of walking, the related control methods are researched (LU Xing hua, 2016).

The stability control of the walking gait of the bionic machine leg is taken based on the measurement of the information of the physical environment parameters of the bionic machine leg. Inertial attitude measurement and behavior parameter analysis of biomimetic robot legs are carried out through sensor devices and sensing elements (LI Ke, 2016). Combined with information fusion and processing methods, adaptive modulation of control parameters is realized, it can provide data input basis for stability control of walking gait of bionic machine legs. On the basis of sensor information collection, the attitude parameters of the acquired machine leg are fused and the qualitative processing is made, combining kinematics and mechanics analysis to realize the optimization of control law. In traditional methods, the gait control method of machine legs mainly adopts fuzzy control and integral control method (GAO Shan, 2015). It is easy to be influenced by the disturbance of machine legs and the nonlinear disturbance of joint torque, which leads to the poor stability of machine legs and the low robustness of control. For example, in reference (Guo, 2015), it has proposed an optimize the fuzzy PID control method of the lower extremity exoskeleton based on the design of adaptive inversion integral controller machine legs, but the control method of robotic leg small disturbance rejection ability is not strong, the robotic leg step of modeling error is big, the actual the control effect is affected. In response to the above problems, a gait tracking control method for machine legs based on damping torque feedback regulation is proposed. Kinematics analysis of the kinematics equation of the machine leg is constructed by three-axis coordinate system model (ZHANG Danfeng, 2017). The adaptive

Huang, P., Lu, X., Huang, W. and Li, Z.
Gait Tracking Control of Machine Leg Based on Damping Torque Feedback Control.
In *3rd International Conference on Electromechanical Control Technology and Transportation (ICECTT 2018)*, pages 541-545
ISBN: 978-989-758-312-4

optimization of the step sensing information of the robot leg with the parameters of the gait motion and the damping torque as the constraint index. An inverse stabilization control method is introduced to modify the error feedback of the gait tracking parameter of the machine leg. The feedback adjustment of damping torque is realized by combining the nonlinear adaptive inversion integral method, and the gait stability tracking control of the machine leg is realized. The simulation results show the superiority of this method.

2 Analysis of the control principle and kinematic model of gait tracking of the machine leg

2.1 Control constraint parameters and control overall structure

The bionic robot legs are affected by the key disturbances and environmental interference of various components during walking, and the small disturbance and disturbance will lead to the instability of walking posture. In order to keep the stability of the walking posture of the bionic machine leg in walking, stability control is required. The realization of control law design is constructed based on the construction of control constraint parameters, and multi-sensor information collection model is used for parameter acquisition of bionic robot leg walking stability control. The sensitive sensor uses three axis bionic robot leg walking tracking control accelerometer, magnetic force sensor and three-axis gyroscope to collect the position and attitude parameter of the machine leg. A new bionic robot leg walking posture parameter information fusion method is established. The gyroscope's angle estimation is taken as the process data, and a delayed two degree of freedom control model is applied to the external electric field stimulation of the robot leg controller, get the distance error function V_E :

$$V_E = \frac{A}{\omega}\sin(\omega t) \tag{1}$$

Wherein, A is the amplitude of the gait oscillation of the machine leg, $\omega = 2\pi f$, f is the external electric field frequency applied, the controlled constraint parameter model of the machine leg is divided into two parts, the reference factor and the non-reference factor, and the external electric field current is introduced into the attitude sensitive element of the controller:

$$I_E = C_m A\cos(\omega t) \tag{2}$$

For different sensitive characteristic parameters, the oscillation characteristic of the step in the step of the machine leg under the unknown disturbance has the nonlinear characteristics, Feature sampling is carried out according to the periodic discharge method of the sensitive element. The chaotic eigenvalue of the fusion parameters of the steady state of the robot leg is extracted and the amplitude of the stimulus is stimulated as $A = 2.5mV$, applying an external control signal u , by analyzing the constraint parameters of closed loop PI type iterative learning method to realize machine leg step control, a closed loop PI iterative learning method to realize the constraint parameter analysis of step control of the machine leg, the constraint parameter model of the gait tracking control by the main HH neuron model can be expressed as:

$$\begin{cases} \dot{V}_m = -[I_{E,m} + g_{Na} m_m{}^3 h_m (V_m + V_{E,m} - V_{Na}) \\ \quad + g_k n_m{}^4 (V_m + V_{E,m} - V_k) + g_L (V_m + V_{E,m} - V_L)] / C_m \\ \dot{m}_m = \alpha_m (V_m)(1 - m_m) - \beta_m (V_m) m_m \\ \dot{h}_m = \alpha_h (V_m)(1 - h_m) - \beta_h (V_m) h_m \\ \dot{n}_m = \alpha_n (V_m)(1 - n_m) - \beta_n (V_m) n_m \end{cases} \tag{3}$$

Taking the sampling parameter of the sensitive element of the input layer of HH neuron as the research object, we amplify the amplitude of the stimulation current by two times, and use the damping moment as input parameter in iterative learning:

$$\begin{cases} \dot{V}_s = -[I_{E,s} + g_{Na} m_s{}^3 h_s (V_s + V_{E,s} - V_{Na}) + g_k n_s{}^4 (V_s + V_{E,s} - V_k) \\ \quad + g_L (V_s + V_{E,s} - V_L)] / C_m + u \\ \dot{m}_s = \alpha_m (V_s)(1 - m_s) - \beta_m (V_s) m_s \\ \dot{h}_s = \alpha_h (V_s)(1 - h_s) - \beta_h (V_s) h_s \\ \dot{n}_s = \alpha_n (V_s)(1 - n_s) - \beta_n (V_s) n_s \end{cases} \tag{4}$$

In the process of tracking the gait of the machine leg, the ability to follow the reference trajectory $y_d(t)$ perfectly, thus improve the performance of gait tracking control of the machine leg (XU Wei-min, 2016).

2.2 A bionic kinematic model of a machine leg

On the basis of the constructed model of the controlled object of the bionic machine leg, the kinematic equation is analyzed, the kinematic equation of the bionic machine leg is described by using the RRT motion planning model (HE Da-kuo, 2016):

$$m\frac{dV}{dt} = P\cos\alpha - X - mg\sin\theta \tag{5}$$

$$mV\frac{d\theta}{dt}=P\sin\alpha+Y-mg\cos\theta \tag{6}$$

$$J_z\frac{d\omega_z}{dt}+(J_y-J_x)\omega_y\omega_x+J_{xy}(\omega_y^2-\omega_x^2)=M_z \tag{7}$$

$$\frac{dx}{dt}=V\cos\theta \tag{8}$$

$$\frac{dy}{dt}=V\sin\theta \tag{9}$$

$$\frac{d\vartheta}{dt}=\omega_z \tag{10}$$

$$\alpha=\vartheta-\theta \tag{11}$$

$$\delta_z=f(e_1) \tag{12}$$

Wherein, θ is the inclination of the bionic machine leg centroid and the target shape vector *V*, ϑ is the longitudinal inclination of the walking gait of a bionic machine leg. x, y are bionic machine leg centroid positions.

3 Optimization of gait tracking control algorithm for machine legs

3.1 Resistance torque feedback regulation

On the basis of above gait tracking control, constraint parameter analysis and kinematic model construction, gait motion mechanics and damping moment parameters are taken as constraint indexes to achieve adaptive optimization of stepping sensing information of machine legs, gait tracking error feedback control is obtained, it is assumed that the walking motion of the bionic machine leg is a longitudinal linear motion model, the centroid of the bionic machine leg is the origin of the coordinate system, and the potential error of the gait tracking is defined as follows:

$$e_V=V_m-V_s \tag{13}$$

According to the relationship between the damping torque and the gait coordinated control, the boundary coupling control integral method is applied to the steady-state error compensation in the synchronous control of the gait of the machine legs, the walking tracking error of the bionic robot leg is output in two non-coupled control integral elements: $e_x=x-x_d, e_\theta=\theta-\theta_d$, wherein x_d, θ_d are steady state tracking errors of reference moment, under the condition of limited initial integration, the adaptive inverse integral control is adopted, and the dynamic equation of the *K* iteration can be written.:

$$\begin{cases}\dot{x}_k(t)=f(t,x_k(t),u_k(t))\\ y_k(t)=g(t,x_k(t))+D(t)u_k(t)\end{cases} \tag{14}$$

The *K* tracking error is:

$$e_k(t)=y_d(t)-y_k(t) \tag{15}$$

Adaptive quantization fusion processing is taken by using closed loop PI learning method, then:

$$u_{k+1}(t)=u_k(t)+k_pe_{k+1}(t)+k_i\int_0^t e_{k+1}(s)ds \tag{16}$$

With the above process, the damping torque parameter is taken as the constraint index to optimize the stepping sensor information of the robot legs, so as to achieve feedback regulation of the torque and improve the tracking stability of the robot legs.

3.2 Optimization of gait tracking control law for machine legs

Combined with nonlinear adaptive inversion integral method, the feedback regulation of damping torque is realized, and the optimal control of robot leg gait tracking control is achieved. The output leg number of robot leg gait tracking control structure is *m*, performance index function of robot leg step sensing information optimization is:

$$F(x)=\sum_{q=1}^{Q}e_q^Te_q=\sum_{q=1}^{Q}\sum_{k=1}^{m}e_{kq}^2=\sum_{i=1}^{N}v_i^2 \tag{17}$$

The e_q is the desired output attitude parameter of the *q* samples and the error of the inertial fusion parameter, the parameter correction vector of the gait tracking of the leg is obtained by using the inverse stabilization control method:

$$x^T=[w_{11},\cdots,\ w_{tn},z_{11},\cdots,z_{mt}] \tag{18}$$

According to the nonlinear adaptive inversion integral method, the Jacobi matrix can be written as a quantitative fusion of the attitude parameters of the machine gait tracking:

$$J(x)=\begin{pmatrix}\frac{\partial e_{11}}{\partial w_{11}} & \frac{\partial e_{11}}{\partial w_{12}} & \cdots & \frac{\partial e_{11}}{\partial z_{mt}}\\ \frac{\partial e_{21}}{\partial w_{11}} & \frac{\partial e_{21}}{\partial w_{12}} & \cdots & \frac{\partial e_{21}}{\partial z_{mt}}\\ \vdots & \vdots & \ddots & \vdots\\ \frac{\partial e_{mQ}}{\partial w_{11}} & \frac{\partial e_{mQ}}{\partial w_{12}} & \cdots & \frac{\partial e_{mQ}}{\partial z_{mt}}\end{pmatrix} \tag{19}$$

The general term is:

$$\begin{aligned}\frac{\partial e_{dq}}{\partial z_{kj}}&=\frac{-\partial Y_{dq}}{\partial z_{kj}}=-\frac{\partial g(o_{dq})}{\partial z_{kj}}\\ &=-g'(o_{dq})\frac{\partial\left(\sum_{j=1}^{t}z_{dj}a_{jq}\right)}{\partial z_{kj}}\end{aligned} \tag{20}$$

The steady state of the walking attitude of the machine leg is the constraint condition of the independent variable control, set:

$$\dot{\sigma_i} = \begin{cases} \mu \sin \dfrac{\pi e}{2\mu}, |e_i| < \mu \\ \mu, |e_i| \geq \mu \quad\quad (\mu > 0 \\ -\mu, |e_i| \leq -\mu \end{cases} \tag{21}$$

According to the normal correlation between the steady state disturbance $\boldsymbol{w}(k)$ and the acceleration measurement matrix $\boldsymbol{u}_i(k)$ based on the walking posture of the robot leg, the information state of the walking posture of the machine leg is updated:

$$\begin{cases} \hat{\boldsymbol{y}}(j,k|k) = \hat{\boldsymbol{y}}(j-1,k|k) + \breve{\boldsymbol{H}}_j^T(k)\boldsymbol{R}_j^{-1}(k)\breve{\boldsymbol{M}}_j(k) \\ \boldsymbol{Y}(j,k|k) = \boldsymbol{Y}(j-1,k|k) + \breve{\boldsymbol{H}}_j^T(k)\boldsymbol{R}_j^{-1}(k)\breve{\boldsymbol{H}}_j(k) \end{cases} \tag{22}$$

Wherein, $\hat{\boldsymbol{y}}(0,k|k) = \hat{\boldsymbol{y}}(k|k-1)$, $\boldsymbol{Y}(0,k|k) = \boldsymbol{Y}(k|k-1)$, and:

$$\begin{aligned} \boldsymbol{Y}(k|k) &= \boldsymbol{Y}(N,k|k) \\ &= \boldsymbol{Y}(k|k-1) + \sum_{j=1}^{N} \breve{\boldsymbol{H}}_j^T(k)\boldsymbol{R}_j^{-1}(k)\breve{\boldsymbol{H}}_j(k) \\ &= \boldsymbol{Y}(k|k-1) + \breve{\boldsymbol{H}}^T(k)\boldsymbol{R}^{-1}(k)\breve{\boldsymbol{H}}(k) \end{aligned} \tag{23}$$

In a comprehensive analysis, the gait stability tracking control of the machine leg is realized through the feedback adjustment of the damping torque.

4 Simulation experiment

In order to test the application performance of this method in the implementation of the bionic robot leg walking stability control, the simulation experiment is carried out, the experiment is designed by Matlab, using digital magnetometer, accelerometer and gait parameters of three axis gyroscopes. The measurement error of the acquisition of the original attitude parameter of the machine leg by three kinds of sensitive elements is set respectively. 2mm, 1.2mm and 1.2mm. The initial position of the machine leg is $\boldsymbol{x}_0 = [1 \quad 0]^T$, $\boldsymbol{p}_0 = \begin{bmatrix} 1 & 0 \\ 0 & 0.1 \end{bmatrix}$, adaptive control parameters are: $\lambda_1 = 1, \lambda_2 = 1, c_1 = 2, c_2 = 2$, the intensity of the error disturbance $\boldsymbol{Q}(k) = 0.25$, the system equation parameters of the gait tracking control model of the machine leg are set as follows: $K_m = 0.0508\text{N.m/V}$, $K_e = 0.5732\text{V}_\text{s}\text{/rad}$, $\boldsymbol{A} = \begin{bmatrix} 1 & 0.6 \\ -0.4 & 0.5 \end{bmatrix}$, $\boldsymbol{B} = \begin{bmatrix} 1 \\ 1 \end{bmatrix}$, $\boldsymbol{C} = [1 \quad 1]$, $\boldsymbol{D} = 0.1$, $\Delta\boldsymbol{A}_1 = \begin{bmatrix} 0.02 & 0.01 \\ -0.02 & 0.12 \end{bmatrix}$, $\Delta\boldsymbol{B}_1 = 0$, $J_p = 0.804(1 \pm 0.5) kg \cdot m^2$, according to the above simulation environment and parameter setting, the robot leg gait tracking control simulation is carried out, and the speed, acceleration, displacement and damping force of the machine legs are obtained. The results are shown in Figure 1.

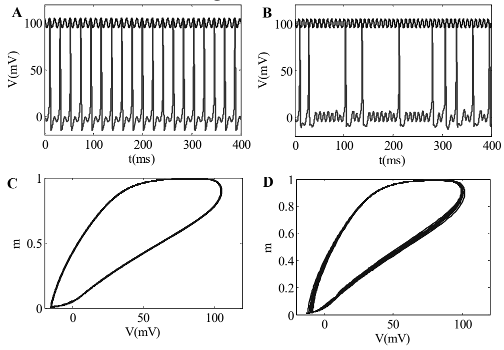
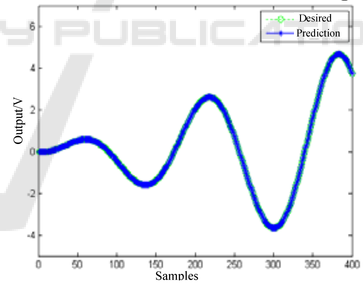
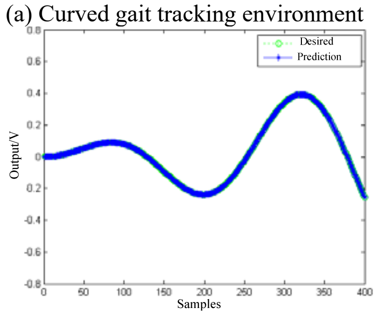


Fig.1 Parameter acquisition of robot leg gait tracking

Taking the gait parameter collected from machine legs collected from Figure 1 as input data, gait tracking, stability control and simulation test are carried out, and the predicted output and expected output of gait tracking function in two groups of test environment are obtained, as shown in Figure 2.



(a) Curved gait tracking environment



(b) Linear gait tracking environment

Fig.2 Output of tracking function of machine leg gait in different environments

Figure 2 analysis showed that in two different test conditions, this method of robotic leg gait tracking accuracy is higher, which in a straight-line walking condition, stability better track machine leg gait, walking in curved environment, this paper through the method of feedback correction and error adjustment of damping torque. With the same attitude parameters good tracking performance. In order to compare the performance of different control methods, the control convergence is taken as the test index, and the contrast results are obtained, as shown in Figure 3, the analysis shows that this method has better convergence, higher stability and better performance improvement in gait tracking control of machine legs.

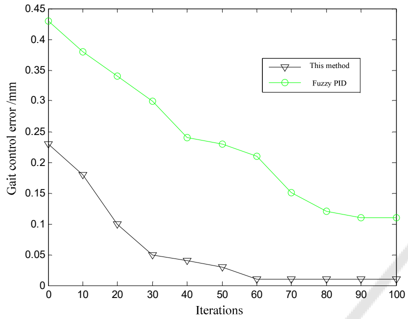


Fig. 3 Control convergence comparison of different methods

5 CONCLUSION

In this paper, the robust control of gait of the legs is studied to improve the robustness of the bionic gait control and the stability of walking. A gait tracking control method based on damping torque feedback is proposed in this paper. The adaptive optimization of the step sensing information of the robot leg with the parameters of the gait motion and the damping torque as the constraint index. An inverse stabilization control method is introduced to modify the error feedback of the gait tracking parameter of the machine leg. The feedback adjustment of damping torque is realized by combining the nonlinear adaptive inversion integral method, and the gait stability tracking control of the machine leg is realized. The simulation results show that the control performance is good.

ACKNOWLEDGEMENTS

This project is supported by and 2017 Undergraduate Scientific and Technological Innovation Project Fund of Guangdong Province (pdjh2017a0938).

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