Gait Stabilization Control Method of Machine Leg Based on Multi Sensor Tracking Fusion

Lu Xing-hua*, Huang peng-fen, Huang hao-hong, Lin jia-cong

1Huali College Guangdong University of Technology, Guangdong Guangzhou, 511325, China
*Corresponding author E-mail: xhlu@gdut.edu.cn

Abstract—In the course of walking, the machine leg is disturbed by the parameters and the influence of the mechanical parts, which leads to the poor stability of the walking. In order to improve the gait stability of the robot leg, a gait stability control method based on multi-sensor tracking fusion is proposed. Multi-sensor data acquisition method is used to collect the attitude information of the machine leg, fusion of attitude parameters is taken based on Kalman filtering algorithm, the fusing attitude information of the robot leg is input into the time-delay damping controller to compensate the error of the attitude parameter in the motion of the robot leg. The feedback control of the walking gait of the machine leg is realized and the adaptive control method is used to improve the stability control performance of the gait of the machine leg. The simulation results show that this method is effective for the gait stability control of machine legs, and the output of machine legs is stable and accurate, which improves the stability and robustness of machine legs.

1. Introduction

A robot leg is a robot that walks through a wireless remote controlling device, with the development of artificial intelligence technology, the autonomous control ability of the machine leg is enhanced and the intelligence of the machine leg is constantly improved. Now, the machine legs are widely used in the fields of industrial production, loading and unloading operations, and soccer robot control. Because of the strong maneuverability of the machine leg, it also has great application value in the field of military investigation, field detection and search and rescue operation. In the research and design of the robot leg, the stability control is the key to ensure the robot leg to complete the related work. The paper studies the gait stability control method of the machine leg. It has great significance to improve the stability and stability of the robot leg[1].

Walking stability of robotic leg control method is taken based on data acquisition and information fusion of the attitude parameter of the machine leg, the multisensor fusion processing method is used to collect the parameters of the walking step of the machine leg. The related fuzzy control method is used for the error correction and parameter adaptive adjustment, so as to improve the stability control performance of the machine leg. Traditionally, the fixed attitude adjustment methods include the inverse control method, the fuzzy PID control method and so on[2-4], early, Smith control method is proposed for time-delay control machine leg, combining the two degree of freedom fitting method with time delay[5], the gait stability control of machine legs is carried out to improve the walking stability of machine legs, but the cost of the control method is large, and the stability and control performance of machine legs is not good. In the reference [6], a closed loop control method based on fuzzy Smith control is proposed. The fuzzy neural network controller is added to the Smith controller to adjust the parameters of the machine leg. The error compensation performance of the machine leg is improved by
error feedback method, but the stability control performance of the machine leg is not good when the model is uncertain.

In order to solve the above problems, this paper proposes a method of stabilizing the gait control of the machine leg based on multi-sensing tracking fusion. Multi-sensor data acquisition method is used to collect the attitude information of the machine leg, fusion of attitude parameters is taken based on Kalman filtering algorithm, the fusing attitude information of the robot leg is input into the time-delay damping controller to compensate the error of the attitude parameter in the motion of the robot leg. The feedback control of the walking gait of the machine leg is realized and the adaptive control method is used to improve the stability control performance of the gait of the machine leg. Finally, the simulation experiment shows the superior performance of this method in improving the stability control of the machine leg.

2. Control object description and attitude parameter multisensor information fusion processing

2.1 Object description of gait control of machine leg

In order to control the gait stability of the machine leg, the sensors are first used to collect the attitude information. Firstly, error compensation and filtering of sensor data are read, and the appropriate algorithm is used to calculate the corresponding attitude angle, three-axis accelerometer, attitude information acquisition machine leg magnetometer and the three-axis gyro sensor are used for data collection[7], assume \( Y \) is dependent variables for gait stability control of robot legs, \( X_1, X_2, \cdots, X_{m-1} \) are \( m-1 \) control independent variables of gait stability for \( Y \), and they have a linear relationship:

\[
Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 \cdots + \beta_{m-1} X_{m-1} + e
\]  

(1)

Wherein, \( e \) is attitude sensor information fusion error, it indicates the influence of factors other than independent variables on \( y \) and the error of test or measurement. It is assumed that the disturbance error of the stability control of the gait of the machine leg is the observed value of the \( N \) Group:

\[
(x_{i1}, x_{i2}, \cdots, x_{i(m-1)}, y_i), i = 1, 2, \cdots, n
\]  

(2)

Quantized tracking items for attitude Information acquisition is:

\[
\begin{align*}
Y_i &= \begin{bmatrix} 1 & x_{i1} & \cdots & x_{i(m-1)} \end{bmatrix} \begin{bmatrix} \beta_0 \\ \beta_1 \\ \vdots \\ \beta_{m-1} \end{bmatrix} + e_i \\
&= X_i \beta + e_i
\end{align*}
\]  

(3)

And the error term \( e \) satisfies the Gauss Markov assumptions. The accelerometer and magnetometer are used to calculate the attitude angle, the disturbance term controlled by the gait of the machine leg is rewritten into a matrix form:

\[
Y = X \beta + e
\]  

(4)

Wherein, \( Y \) is \( n \times 1 \) observation vector, \( X \) is \( n \times m \) positive attitude angle estimation matrix, \( \beta \) is \( m \times 1 \) parameter vector, \( e \) is \( n \times 1 \) dimensional Random error vector.

Thus, the control of the gait stability of the machine leg is converted to the least square fitting problem. Estimation of attitude error deviation of the \( \beta \) is calculated, make \( \| Y - X \beta \| \) reach the minimum, wherein, \( \| \| \) represents the F norm in the Euclidean norm, calculate:

\[
\min_{\beta} \| Y - X \beta \|
\]  

(5)

The steady-state error is introduced and the corresponding attitude angle is calculated. The Kalman filter is used for the original data of the sensor to improve the stability of the control.
2.2 Multi-sensor Information Fusion processing of attitude parameters

Accelerometers and magnetometers are used to calculate the attitude angle of the machine legs, the greater the error of the sensitivity function, the worse the control performance. The control object of the machine leg is decomposed into two control links of certainty and uncertainty they are $G_m(s)e^{-\lambda_1s}$ and $G_m(s)$. According to the two control points respectively to construct a group delay model with two degrees of freedom of the multi-sensor information fusion machine leg gait stability control treatment, gyroscope data are output to Kalman filtering, attitude stability control is taken, the nonlinear coupled Levenberg-Marquardt control equation is constructed[8], and the time delay state equation of the gait stability tracking control is described as:

$$C_1(s) = \frac{\lambda_1s + 1}{\lambda_2s + 1}$$
$$C_2(s) = \prod_{i=1}^{m} \left( \frac{T_m s + 1}{K_m s} \right) (\lambda_2 + L_m) s$$

(6)

Wherein, $\lambda_1$ and $\lambda_2$ are filter time constants, $K_m$ is updated step length, $L_m$ is open loop transfer gain coefficient of gait tracking control, $T_m$ is dead time. The transfer function is obtained by adding pure lag link to inertia link:

$$P(s) = \frac{K_m e^{-L_m s}}{\prod_{i=1}^{m} (T_m s + 1)}, T_m > 0$$

(7)

By adjusting the $\lambda 1$ and $\lambda 2$ to get the sensitivity of robotic leg gait control, to ensure the stability of the control system, error compensation and iterative control are carried out on the gait tracking sensor data of the machine legs, and the conditions of maintaining the stability of the gait control system of the machine legs are obtained:

$$0 < \Delta K < 1 + \frac{\lambda_2}{L_m}$$

(8)

Set performance index function $F(x) = E\left[ \sum_{t=1}^{\infty} e_t^2 \right] = E[e^T e]$, wherein e is the error term for the stability control of the bionic gait of the machine leg, the fusion of attitude parameters is combined with the Kalman filtering algorithm, which reduces the attitude adjustment error of the machine leg and ensures the stability of the output of the gait parameters[9].

3 Optimization of gait stability control method for machine legs

3.1 Kalman filtering algorithm

On the basis of the robotic leg gait control object description in the above, combined with the fusion Kalman filtering algorithm and attitude parameters, the optimization method is researched to improve the design of control algorithm. In this paper, a gait stability control method based on multi sensor tracking fusion is proposed. Taking the lateral displacement of machine legs as the measurement noise covariance of filtering and fusion, we construct two degree of freedom control with time delay[10], the fuzzy adaptive coupling membership transfer function of a time delay two degree of freedom control system is obtained.

$$f_\theta = f\tan(x_i(k) - v(k), x_j(k), r, h_i)$$
$$x_i(k + 1) = x_i(k) + h x_i(k)$$
$$x_j(k + 1) = x_j(k) + h y_h$$

(9)

Input Vector for gait Stability Control of Machine legs is $X(x_1, x_2, \ldots, x_n)$, according to the
condition of stability convergence, while \( g_i^T \Delta x_k = \alpha g_i^T p_k < 0 \), make \( p_k = g_i \), the Kalman filter function of the gait stability control of the machine leg is:

\[
\min_{\beta} |y(t) - X(t)| = \min_{\beta} \left| \begin{array}{c}
    U_i y_i - \Sigma_y V_i \beta \\
    W_i y_i - \Sigma_w V_i \beta \\
\end{array} \right| = \min_{\beta} |y(t+1) - X(t+1)|
\]

(10)

\[
\begin{align*}
\text{Set the rank of } X_i & = r_0, r \leq m, \text{then dimensions of } U_y, V_y \text{ are } r_0 \times r_0, N_y \times r_y \text{ and } m \times r_y, \text{it is known that the n order multiple input and multiple output (MIMO) system for the heading correction control for each walking state is described as follows:}
\end{align*}
\]

\[
y^{(n)} = f(y^{(n-1)}, \ldots, \hat{y}, t) + \Delta f(y^{(n-1)}, \ldots, \hat{y}, t) + d(t) + b(y^{(n-1)}, \ldots, \hat{y}, t)u
\]

(11)

Wherein, \( y \in \mathbb{R}^n \) is the identification vector of the gait control system of the machine leg; \( f \in \mathbb{R}^n \) is attitude tracking Matrix with known attitude parameters, \( u \in \mathbb{R}^n, b \in \mathbb{R}^n \), and meets \( \text{rank}(b) = m \). \( \Delta f \) and \( d(t) \) are parameter uncertain external disturbances of walking control system of the machine leg, and meets:

\[
|\Delta f(X,t)| \leq F(X,t), \quad |d(t)| \leq D(t)
\]

(12)

For the convenience of analysis, Kalman fusion filtering method is used for parameter adjustment. With the above processing, the continuous Kalman filter is used to estimate the attitude of the machine leg, which can effectively improve the accuracy of the estimation of the attitude angle of the machine leg.

3.2 Optimization of robotic leg gait stability control law

The 3-axis accelerometer, magnetometer and 3-axis gyroscope integrated attitude measurement, multi sensor tracking information fusion, equation of state machine design and control leg gait stability is:

\[
\sigma(X,t) = CE - CP(t)
\]

(13)

In the formula, \( C \in \mathbb{R}^{m \times n} \), the inverse integral function of multisensor information fusion is continuous for time, and \( C_{j,i} = 1, 2, \ldots, n; j = 1, 2, \ldots, m \) are positive constants, \( p(t) = (p(t), p(t), \ldots, p(t)) \). Then the machine leg stability control equation for parameter adjustment is \( p(t) = (p(t), p(t), \ldots, p(t)) \), and \( p(t) \) satisfies the following assumptions:

The attitude information of the fusion machine leg is input into the time-delay damping controller, and the error compensation of the attitude parameter in the walking of the machine leg is made, when \( t = T \), then the machine leg is in a steady state, \( p(t), p(t), \ldots, p(t) \) are 0, thus determine the robotic leg gait trajectory energy profile corresponding to the angle of sliding surface, Terminal derivation is:

\[
\sigma(X(t)) = CE - CP(t) = C \left[ \dot{\phi} \dot{\phi} \cdots \dot{\phi} \right] - C \left[ \dot{p}(t) \dot{p}(t) \cdots \dot{p}(t) \right] = C \left[ \dot{\phi} \dot{\phi} \cdots \dot{\phi} \right] + \sum_{i=1}^{m+1} C_i \left[ \dot{e}^i - \dot{e}^i \right]
\]

(14)

Lyapunov function is \( V = \frac{1}{2} \sigma^T \sigma \), The energy gradient of the gait stability control of the robot leg can be obtained by the derivation of the Lyapunov function:

\[
\dot{V} = \sigma^T \sigma = \sigma^T \sigma C_j \left[ f(X(t)) - \dot{\phi} \right] + C \sum_{i=1}^{m+1} C_i \left[ \dot{e}^i - \dot{e}^i \right] + \sigma^T \sigma b(X)u + \sigma^T \sigma \Delta f(X,t) + d(t)
\]

(15)

Because \( \sigma^T C_i \sigma = \| \sigma_i \|^2 \), the correction deviation of the whole control surface walking on the machine leg is satisfied:
Through the above analysis, feedback control is carried out for the walking gait of machine legs, combined with adaptive adjustment method, the gait stability control performance of machine legs is improved, and the gait stability control of machine legs is realized.

4 Simulation experiment

In order to test the application performance of the control algorithm designed in this paper in the control of the gait stability of the machine leg, the simulation experiment is carried out. The simulation experiment is taken based on the environment of Matlab 7.0, and the hardware environment of the simulation experiment is: Matlab 3410b. The processor is Intel Core2 Duo 1.56 GHz, 1 gigabyte of memory, Maximum real eigenvalue is $\hat{\lambda}_{\text{max}}=3.0649$, corresponding eigenvector of $\hat{\lambda}_{\text{max}}$ w is obtained after normalization: $w=[0.0719, 0.6491, 0.2790]$. Suppose the initial speed of the walking of the machine leg is 0.4m/s, displacement offset is 1.45rad, the angle of the horizontal rudder is 32rad, set the attitude information sampling period is 0.02s, Kalman filter cycle is 14.3s, according to the above simulation parameters, the gait stability control simulation experiment of the robot leg is carried out, and the original gait track of the robot leg is obtained as shown in Figure 1.

In Figure 1, the gait walking track of the machine leg is messy and irregular, indicating that the gait stability is not high. The new method in this paper is used to control the stability of the leg, and the optimized output is shown in Figure 2.

The analysis of Figure 2 shows that this method is used to control the gait stability of the machine leg. The trajectory of the machine leg is good, and the steady state tracking ability is strong. Finally, in order to compare the performance of different methods, the convergence error of gait stability control of machine legs is compared with the traditional FCM algorithm and Wolf control method, as shown in Figure 3. The control time delay is shown in Figure 4.
Analysis of Figures 3 and 4, the results show that the method of error of machine leg gait control is low and the delay is short, it can improve the stability control of the robotic leg and real-time control ability.

5 Conclusions
In this paper, the stable gait control of robot leg is studied. In order to improve the gait stability of the robot leg, a gait stability control method based on multi-sensor tracking fusion is proposed. Multi-sensor data acquisition method is used to collect the attitude information of the machine leg, fusion of attitude parameters is taken based on Kalman filtering algorithm, the fusing attitude information of the robot leg is input into the time-delay damping controller to compensate the error of the attitude parameter in the motion of the robot leg. The feedback control of the walking gait of the machine leg is realized and the adaptive control method is used to improve the stability control performance of the gait of the machine leg. The simulation results show that this method is effective for the gait stability control of machine legs, and the output of machine legs is stable and accurate, which improves the stability and robustness of machine legs. It shows good application value in practice.

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