Hybrid Control of 5-Link Biped Robot Using a Wavelet Neural Network

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Abstract - Generally, biped walking is difficult to control because a biped robot is a nonlinear system with various uncertainties. In this paper, we propose a hybrid control system to improve the efficiency of position tracking performance of biped locomotion. In our control system, the wavelet neural network (WNN) based on Sliding mode controller is used as a main controller which estimates a biped robot model, and the compensated controller is proposed to compensate the estimation error. A WNN is utilized to estimate uncertain and nonlinear system parameters, where the weights of WNN are trained by adaptive laws that are induced from the Lyapunov stability theorem. Finally, the effectiveness of the proposed control system is verified through computer simulations.

2 The 5-link Biped Robot Model

The 5-link biped robot model used in this paper is shown in Fig.1. Each link is connected by a rotating joint, which is driven by an independent DC motor.
and $r_\theta$ is generalized torque which is corresponding to each joint angle. $H(\theta)$ is a $5 \times 5$ symmetric positive-definite inertia matrix, $B(\theta, \dot{\theta})$ is a $5 \times 1$ column vector with respect to the Coriolis and centripetal torque, and $G(\theta)$ is a $5 \times 1$ gravity vector.

If $q_1, q_2, q_3$ and $q_4$ are relative angle deflections of the corresponding joint, then $q_1 = \theta_1 - \theta_2, q_2 = \theta_2 - \theta_3, q_3 = \theta_3 - \theta_4, q_4 = \theta_4 - \theta_5$. 

(1) is transformed by $q$, then (1) is expressed as

$$H(q)q + B(q, \dot{q}) + G(q) = r_\theta$$

(2)

### 3. Hybrid Control of Biped Robot

#### 3.1 Wavelet Neural Network

In this paper, we use two WNN estimators in each joint: the one is used to estimate a function of gravity, Coriolis and disturbance, and the other is to estimate a function of inertia matrix.

In our control system, we predict parametric variations and uncertainties in each joint. A proposed WNN structure is shown in Fig. 2.

![Wavelet Neural Network](image)

**Fig. 2 Wavelet Neural Network**

The signal propagation and basic function in the product layer is expressed as

$$yj = \sum_{i} \phi(net_{ip}) \text{ with } net_{ip} = \frac{x_p - m_p}{d_p},$$

(3)

where $x_p$ denotes the input of the WNN, and $m_p, d_p$ are translation and dilation vector of the product layer. Then, outputs sum products of training weight and output of mother wavelet function ($\phi(x) = -x \exp(-x^2/2)$)

$$y^j = \sum_{i} w_j^{ip} y_i \text{ with } j = 1, 2, \ldots, n \text{ and } o_1, o_2 = 1, 2, \ldots, 5,$$

(4)

where, $n$ is the number of wavelet node, $w_j^{ip}$ is the weight vector between product layer and the output layer, $j$ is the number of wavelet node, and $i$ is the number of joint. Outputs are $y^1 = \hat{X}$ and $y^2 = \hat{Y}$.

The weighting vector is as the follows:

$$\hat{X}(e|C) = \hat{C}^T \text{ and } \hat{Y}(e|D) = \hat{D}^T,$$

(5)

where, $\Gamma = [y^{o_1}, y^{o_2}, \ldots, y^{o_5}]$ and $\hat{Y} = [y^{o_1}, y^{o_2}, \ldots, y^{o_5}]$ is output vector of wavelet function. $\hat{C} = [w_{1}, w_{2}, \ldots, w_{5}]$ and $\hat{D} = [\delta_1, \delta_2, \ldots, \delta_5]$ is weight vector which is trained by tuning algorithm. Optimal weight vector, which performs the perfect approximation, is as follows:

$$X^*(e|\gamma) = C^T \text{ and } Y^*(e|\gamma) = D^T.$$

(6)

### 3.2 Hybrid WNN SMC

The control structure which is approximated by hybrid WNN SMC is shown in Fig. 3.

![Hybrid WNN SMC System](image)

**Fig. 3 Structure of a hybrid WNN SMC system**

Theorem 1: Assume that the biped robot model (2) is used for our control system. The proposed control system is designed as (7). Then, the weights of the WNNs are trained by the adaptation laws (8)-(10), the stability of our control system is guaranteed:

$$r_\theta = \hat{X} + \hat{Y}(q_{\gamma} - 2 \lambda \xi e - \lambda^2 \xi e) - E \text{sgn}(e),$$

(7)

$$\hat{C}_r = \lambda \xi \Gamma_3,$$

(8)

$$\hat{D}_r = \lambda \xi \gamma_q (\gamma_{\gamma} - 2 \lambda \xi e - \lambda^2 \xi e),$$

(9)

$$\hat{E}_r = \lambda \xi |e|,$$

(10)

where $\mu$ is a small positive constant, and $\lambda_\xi$, $\lambda_\gamma$ and $\lambda_\psi$ are positive tuning gains.

### 3.3 Simulation of Hybrid Control

The 5-link biped model shown in Fig. 1 is used in this simulation. The planning of the trajectory for a biped robot walking on a horizontal plane surface is divided into three parts: starting step from the vertical position on a horizontal plane surface, steady walking on a horizontal plane surface and walking form start to steady on a horizontal plane surface. The locomotion mode of a biped robot on the horizontal surface has the form shown in Fig. 4. Reference trajectory for a steady stable walking is shown in Fig. 5.
Fig. 4 Reference Trajectory of $\mathbf{q}$.

Fig. 5 Locomotion mode of 5-link biped robot.

Fig. 6 Reference tracking trajectory for a hybrid WNNSMC.

Fig. 7 Variation of the driving torques with time for a hybrid WNNSMC.

Fig. 8 Squared error of a hybrid WNNSMC in each joint for SMC.

Fig. 6 shows reference tracking for hybrid WNNSMC, Fig. 7 shows driving torque, and Fig. 8 shows variation of error. MSE is 0.0016. A hybrid WNNSMC shows a good tracking performance.

4. Conclusion

In this paper, we designed a hybrid WNN control system based on sliding-mode technique for the 5-link biped robotic model in order to improve the efficiency of position tracking performance of biped locomotion. In our control system, hybrid WNNSMC was employed to estimate uncertain and nonlinear functions of the 5-link biped robot. We designed two WNN estimators in each joint. The one was used to estimate a function of gravity, Coriolis and disturbance, and the other was to estimate a function of inertia matrix. Their weights were trained by the adaptation laws induced from the Lyapunov stability theorem, which guarantee the stability of the proposed control scheme. And the compensation controller compensated estimation errors. Through computer simulations, we confirmed that the performance of the hybrid WNNSMC was verified.

REFERENCES