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웨이블릿 신경회로망을 이용한 5링크 이족로봇의 하이브리드 제어

*김철하, **최윤호, *박진배
*연세대학교 전기전자공학과 **경기대학교 전자공학부

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

*Kim Chul Ha **Yoon Ho Choi *Jin Bae Park
*Dept. of Electrical & Electronic Engineering, Yonsei University
**School of Electronic Engineering, Kyonggi University, Suwon, Korea

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.

1. Introduction

In controlling biped robots, we face some problems such as instability of locomotion, high-order dynamic equation, existence of different phases of the walking cycle and various uncertainties. Due to these constraints, a biped robot requires a robust control technique having higher performance in spite of uncertainties comparing with standard PD control. So, a computed torque or inverse dynamics technique using feedback linearization [1,2] is proposed to control a biped robot. However, such methods are difficult to control a biped robot model with the model uncertainties. Therefore, the sliding mode technique for the robust control of a biped robot with uncertainties is proposed [3]. However, the sliding mode control (SMC) requires prior knowledge of the mathematical model and uncertainty bounds.

On the other hand, recently, wavelet neural networks (WNNs), which combine the capability of neural network [4] for learning from processes and the wavelet decomposition are used as good estimation tools for the identification and control of dynamic system. Training algorithm plays important role for WNN approximation. So, training methodology, which is induced by Lyapunov stability theorem ,has researched to ensure the stability, robustness, and performance of system.

In this paper, we propose hybrid control which consists of the WNN based SMC (WNNSMC) [5] and the error compensation controller[6]. In our control system, wavelet neural network is employed to estimate uncertain and nonlinear functions of the 5-link biped robot. All weights of WNN are trained by the adaptation laws induced from the Lyapunov stability theorem, which are used to guarantee the stability of control system. And we design the compensation controller to compensate approximation error. Finally, in order to verify the effectiveness and robustness of the proposed control technique, the performance of control scheme is proved by comparing the tracking performance of the hybrid control with that of the SMC via the 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.

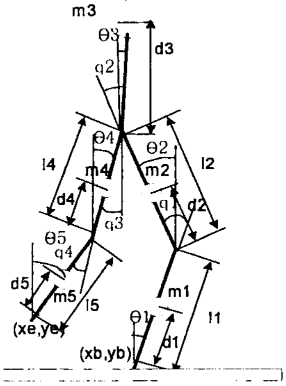

Fig.1 5-link Biped Robot Model

Parameters shown in Figure 1 are as follows:

m_i : Mass of link i,

l_i : Length of link i,

d_i : Distance between the mass center of link i and its lower joint,

I_i : Moment of inertia with respect to an axis passing through the mass center of link i and being perpendicular to the motion plane,

θ_i : Angle of link i with respect to vertical (the positive direction of θ_i, $i=1,2,3,4,5$, is the one shown in the figure).

Dynamic model of biped robot is as follows:

$$H(\theta)\ddot{\theta}+B(\theta,\dot{\theta})+G(\theta)=\tau_\theta \tag{1}$$

where $\theta=[\theta_1,\theta_2,\cdots,\theta_5]^T$, $\tau_\theta=[\tau_{\theta 1},\tau_{\theta 2},\cdots,\tau_{\theta 5}]^T$,

$$B(\theta,\dot{\theta})=col\left[\sum_{j=1}^{5}\left(h_{ij}(\dot{\theta}_j)^2\right)\right],\ G(\theta)=col\left[G_i(\theta)\right],$$

$$H(\theta)=\left[H_{ij}(\theta)\right]\ (i,j=1,2,\cdots,5),$$

and τ_θ is generalized torque which is corresponding to each joint angle. $H(\theta)$ is a 5×5 symmetric positive-definite inertia matrix, $B(\theta,\dot{\theta})$ is a 5×1 column vector with respect to the Coriolis and centripetal torque, and $G(\theta)$ is a 5×1 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

$$H(q)\ddot{q}+B(q,\dot{q})+G(q)=\tau_q \quad (2)$$

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.

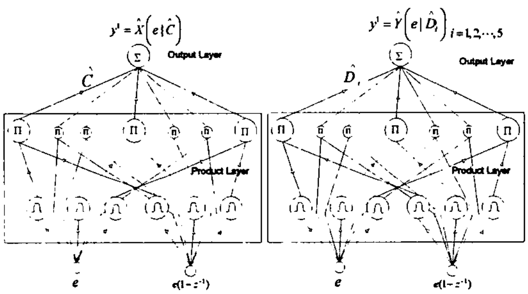

Fig.2 Wavelet Neural Network

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

$$y_i=\prod_j \phi(net_{jp}) \text{ with } net_{jp}=\frac{x_p-m_{jp}}{d_{jp}} \quad (3)$$

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

$$y^o=\sum_j w_{jo}y_j \text{ with } j=1,2,\cdots,n \text{ and } o_1=1,\ o_2=1,2,\cdots,5 \quad (4)$$

where, n is the number of wavelet node, w_{jo} 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 $y^{o1}=\hat{X}$ and $y^{o2}=\hat{Y}$.

The weighting vector is as the follows:

$$\hat{X}(e\,|\,\hat{C})=\hat{C}\Gamma \quad \hat{Y}(e\,|\,\hat{D})=\hat{D}\Upsilon \quad (5)$$

where, $\Gamma=[y^{o1}_1\ y^{o1}_2 \cdots y^{o1}_n]$ and $\Upsilon=[y^{o2}_1\ y^{o2}_2 \cdots y^{o2}_n]$ is output vector of wavelet function. $\hat{C}=[w_{11}\ w_{21}\cdots w_{n1}]^T$ and $\hat{D}=[\omega_{11}\ \omega_{21}\cdots \omega_{n1}]^T$ is weight vector which is trained by tuning algorithm. Optimal weight vector, which performs the perfect approximation, is as follows:

$$X^*(e\,|\,C^*)=C^*\Gamma \quad Y^*(e\,|\,D^*)=D^*\Upsilon \quad (6)$$

3.2 Hybrid WNN SMC

The control structure which is approximated by hybrid WNNS MC is shown in Fig. 3.

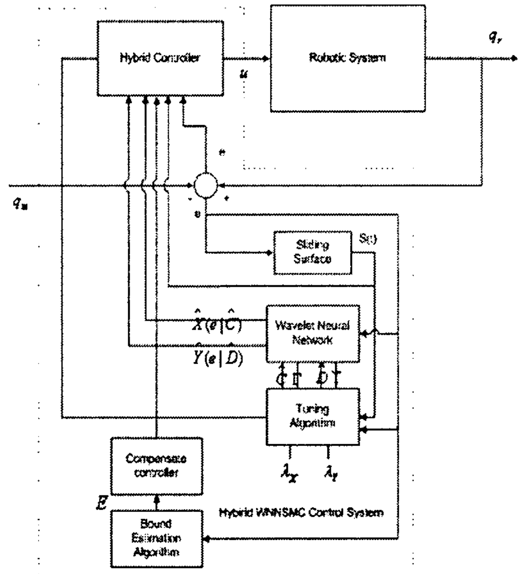

Fig.3 Structure of a hybrid WNNSMC system

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:

$$\tau_i=-\hat{X}_i+\hat{Y}_i(\ddot{q}_{mi}-2\lambda\dot{e}_i-\lambda^2 e)-E_i\,\mathrm{sgn}(s_i), \quad (7)$$

$$\dot{\hat{C}}_i=\lambda_X s_i\Gamma_i, \quad (8)$$

$$\dot{\hat{D}}_i=\lambda_Y s_i\Upsilon_i(\ddot{q}_m-2\lambda\dot{e}_i-\lambda^2 e_i), \quad (9)$$

$$\dot{\hat{E}}_i=\lambda_E\,|\,s_i\,|, \quad (10)$$

where μ is a small positive constant, and λ_X, λ_Y and λ_E 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.

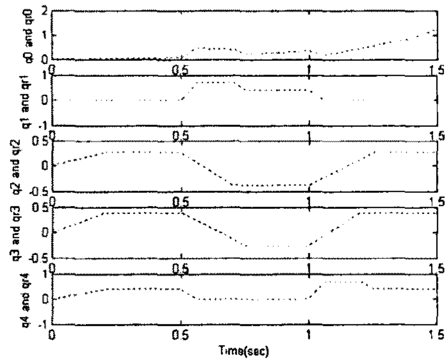

Fig. 4 Reference Trajectory of q.

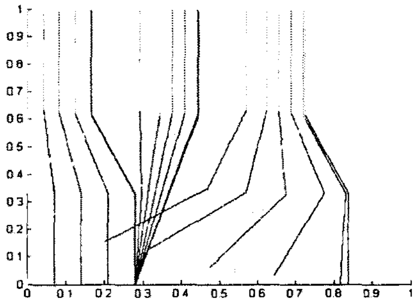

Fig. 5 Locomotion mode of 5-link biped robot.

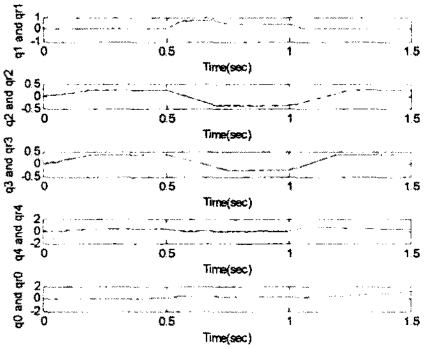

Fig. 6 Reference tracking trajectory for a hybrid WNNSMC.

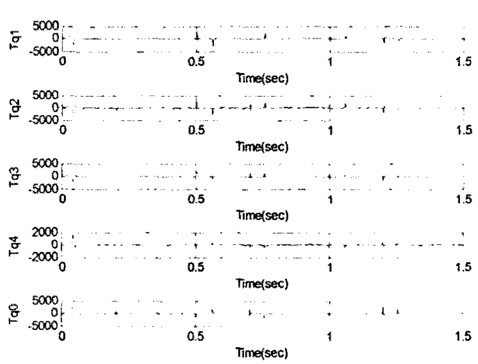

Fig.7 Variation of the driving torques with time for a hybrid WNNSMC

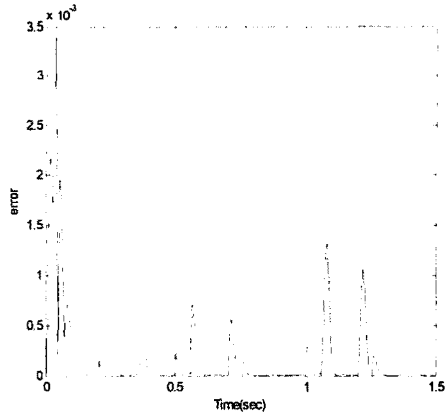

Fig. 8 Squared error of a hybrid WNNSMC in each joint for SMC.

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, Coriollis 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.

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