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Study on genetic fuzzy wavelet neural network controller of robotic manipulator

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Abstract. This paper deals with the tracking controller design of robotic manipulator using genetic algorithm (GA). A genetic fuzzy wavelet neural network (GFWNN) controller is designed and implemented based on MATLAB in this paper, whose parameters are optimized by GA. The structure and algorithm of fuzzy wavelet neural network (FWNN) are described at first. Then the key content of GA used in this paper and the steps for using GA to optimize FWNN are demonstrated. Finally, a numerical simulation of tracking control for 2-link robotic manipulator is given to verify the effectiveness of the proposed method.

Introduction

Nowadays fuzzy control gets the wide attention since it does not depend on the mathematical model and has good robustness. It solved many practical problems. But the determination of fuzzy membership functions and fuzzy rules depends on expert experience and fuzzy control lacks self-learning ability. It is difficult to apply if the expert experience is absent. Neural network is another research hotspot in the artificial intelligence field. Neural network has good ability of self-learning, self-organizing, fault tolerance and approximation, but it lacks the capacity of inductive inference. The fuzzy neural network, combined fuzzy control with neural network, has self-learning and inductive inference ability and good prospects for the development.

Wavelet neural network, proposed by Zhang Qinghua in 1992 [1], is the combination product of wavelet analysis theory and neural network technology. Wavelet neural network has been used in many fields such as function approximation, computer vision and fault diagnosis field since it has good time-frequency localization characteristics, multi-scale resolution property, self-organizing and self-learning characteristics [2-4]. This paper mainly deal with the parameters design of fuzzy wavelet neural network controller, which is based on the integration of fuzzy technology, neural network and wavelet transform technique. The controller is applied to the 2-link manipulator trajectory control. Fuzzy wavelet neural network (FWNN) usually uses the gradient method to train parameters, so it is difficult to avoid the problem of local convergence. Genetic algorithm (GA) is a global optimization algorithm, which is developed by simulating biological evolution process. It provides a new idea for these questions, which are difficult to be solved by the conventional mathematical methods and other artificial intelligence technologies. GA has good robustness and wide applicability. For overcoming the disadvantages of the traditional learning methods, we use GA to optimize FWNN controller' parameters in this paper. A numerical simulation of tracking control for 2-link robotic manipulator is given to verify the effectiveness of the proposed method at last.

Fuzzy Wavelet Neural Network

The structure of FWNN with two input and single output is shown in Fig 1.

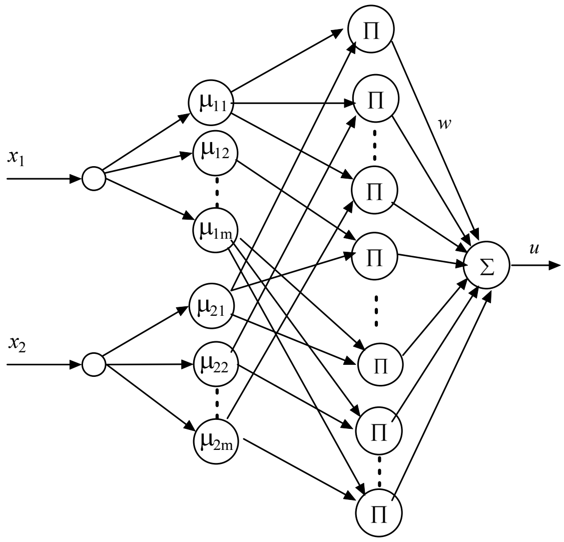

Fig. 1. Structure of fuzzy wavelet neural networks

FWNN consists of four layers: input layer, fuzzification layer, fuzzy inference layer and output layer [5].

The inputs of the input layer are usually the error between expected value and the actual value and the error change rate. The relationship between input and output is shown as follows:

$$O_i^1 = x_i \qquad i = 1,2 \tag{1}$$

The second layer maps inputs into linguistic fuzzy sets with corresponding membership values. In this paper, each input is divided into 3 fuzzy sets, that is m = 3 in Fig. 1. The relationship from input to output is shown as follows:

$$O_{ij}^2 = \mu_{ij}(O_i^1) = \psi(\frac{O_i^1 - b_{ij}}{a_{ij}}) \qquad i = 1,2; j = 1,2,3$$
$$\psi(s) = \cos(1.75s)e^{-s^2/2} \tag{2}$$

where, a_{ij} and b_{ij} are the dilation and translation parameters of the wavelet membership function.

The third layer realizes fuzzy inference operation. The relationship between input and output is shown by the following equation:

$$O_{kj}^3 = O_{1k}^2 \cdot O_{2j}^2 \qquad k = 1,2,3; j = 1,2,3 \tag{3}$$

The fourth layer is defuzzification layer, the output can be calculated by:

$$u = O^4 = \frac{\sum_{k=1}^{3}\sum_{j=1}^{3} w_{kj} \cdot O_{kj}^3}{\sum_{k=1}^{3}\sum_{j=1}^{3} O_{kj}^3} \tag{4}$$

where, w_{kj} is the weight, u is the output.

For the 2-link manipulator control problem, there need two such neural networks. Considering the coupling between links, the coupling output y_j can be calculated by:

$$y_l = \sum_{i=1}^{2} w_{li}^{'} \cdot u_i \qquad l = 1,2 \tag{5}$$

where, $w_{li}^{'}$ is the weight. We can get the crisp controller output through multiplying y_j by the corresponding scale factor.

From above, it can be seen that the following parameters need to be determined: a_{ij} , b_{ij} , w_{kj} and $w_{li}^{'}$, i =1,2;j =1,2,3; k =1,2,3; l =1,2. For the 2-link manipulator controller, there are 46 undetermined parameters.

Genetic Algorithm

Generally, GA has five basic components: coding; initial population generation method; fitness function; genetic operator such as selection, crossover and mutation; parameter value of GA.

The following is the key content of GA used in this paper.

(1) Coding method. Considering the parameters' number, we adopt real coding method.

(2) Fitness function. The fitness function is obtained by transforming the objective function J. in this paper we take IATE index as the objective function. For the control problem of 2-link manipulator, the fitness function F can be expressed as follows:

$$\begin{aligned} J &= \int_0^t | e_1(t) | \, dt + \int_0^t | e_2(t) | \, dt \\ F &= \frac{C}{J + \delta} \end{aligned} \tag{6}$$

where, $e_1(t)$ is the angular error of link 1, $e_2(t)$ is the angular error of link 2, δ is a small positive number, C is a positive number. In this paper we set C = 100 and δ = 0.00001.

(3) Selection operation. We use roulette wheel selection method in this paper.

(4) Crossover operation. The arithmetic crossover operator is employed. Let X^t and Y^t be the two individuals to which are applied crossover operation, the new individuals $X^{t+1}$and Y^{t+1} can be gotten by the following equation [6]:

$$\begin{aligned} X^{t+1} &= \alpha Y^t + (1-\alpha) X^t \\ Y^{t+1} &= \alpha X^t + (1-\alpha) Y^t \end{aligned} \tag{7}$$

where, α is a random number in the range [0, 1].

Along with the evolution of population, the repetitive or similar individual will appear and the population diversity becomes worse. The effect of arithmetic crossover becomes weaker. It will result in prematurity. For dealing with this problem, we introduce a discriminant function:

$$H = F(X) - F(Y) \tag{8}$$

where, $F(X)$ and $F(Y)$ are the fitness function value of individual X and individual Y to which are applied crossover operation. If H = 0, Y^t in Eq. 7 is replaced by an individual generated randomly in solution space.

(5) Mutation operation. The uniform mutation operator is adopted. The equation is as follows:

$$
\begin{aligned}
M_i &= (x_{Ui} + x_{Li})/2 \\
D_i &= (x_{Ui} - x_{Li}) \\
x_i^{'} &= M_i + D_i \cdot (rnd - 0.5)
\end{aligned}
\tag{9}
$$

where, x_{Ui} and x_{Li} are the upper and lower limits of i^{th} dimension parameter x_i, $x_i^{'}$ is the gene after mutation operation, *rnd* is a random number in the range [0, 1].

(6) Elitist preserved strategy. All the genetic operators such as selection, crossover and mutation maybe make the previous best individual lost, so the last individual of the population is replaced by the previous best individual after each operation in this study.

The steps for using GA to optimize FWNN controller are as follows:

(1) Initialize the population size, maximum generation, crossover probability, mutation probability, value range of parameters and Initial population.

(2) Decode the chromosome into FWNN controller parameters, simulate and calculate the fitness function value by Eq. 6.

(3) Compare and obtain the previous best individual.

(4) Apply genetic operator to the population and preserve elitist.

(5) Go back step (2) until the termination condition is satisfied.

Simulation example

In this study, we take 2-link manipulator as the controlled object. The diagram of 2-link manipulator is shown in Fig. 2. The mathematical model can be expressed by the following equation:

$$\tau = M(\Theta)\ddot{\Theta} + V(\Theta,\dot{\Theta}) + G(\Theta) + F(\dot{\Theta}) + T_d(\Theta,\dot{\Theta}) \tag{10}$$

where, $\Theta = [\theta_1 \quad \theta_2]^T, \dot{\Theta} = [\dot{\theta}_1 \quad \dot{\theta}_2]^T, \ddot{\Theta} = [\ddot{\theta}_1 \quad \ddot{\theta}_2]^T$ are the joint position, velocity, and acceleration vectors, $\tau = [t_1 \quad t_2]^T$ is the applied torque; $M(\Theta)$ denotes the moment of inertia, $V(\Theta,\dot{\Theta})$ are the centrifugal and Coriolis force, $G(\Theta)$ includes the gravitational forces, $F(\dot{\Theta})$ is static or dynamic friction matrix, $T_d(\Theta,\dot{\Theta})$ is the uncertainties that is equal to the model error plus external disturbance.

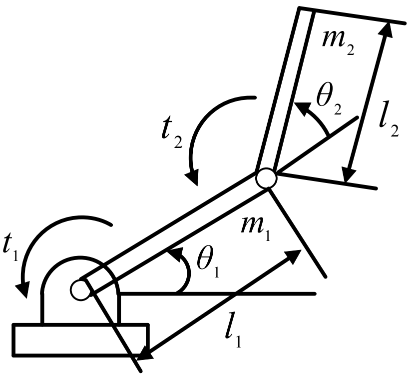

Fig.2. Robot manipulator with two links

M, V, G in Eq. 10 can de described as:

$$M(\Theta)=\begin{bmatrix} m_1l_1^2+m_2(l_1^2+l_2^2+2l_1l_2\cos\theta_2) & m_2l_2^2+m_2l_1l_2\cos\theta_2 \\ m_2l_2^2+m_2l_1l_2\cos\theta_2 & m_2l_2^2 \end{bmatrix}$$

$$V(\Theta,\dot{\Theta})=\begin{bmatrix} -m_2l_1l_2\sin\theta_2\dot{\theta}_2^2-2m_2l_1l_2\sin\theta_2\dot{\theta}_1\dot{\theta}_2 \\ m_2l_1l_2\sin\theta_2\dot{\theta}_1^2 \end{bmatrix}$$

$$G(\Theta)=\begin{bmatrix} m_2l_2g\cos(\theta_1+\theta_2)+(m_1+m_2)l_1g\cos\theta_1 \\ m_2l_2g\cos(\theta_1+\theta_2) \end{bmatrix}$$

where, m_1 and m_2 are masses of link l and link 2 respectively, l_1 and l_2 are lengths of link 1 and link 2, g is the acceleration due to gravitation.

In this paper, the parameters of the 2-link robot are m_1 =8kg, m_2 =2kg, l_1 =1.2m, l_2= 0.8m. Friction matrix is $F(\dot{\Theta})=0.5sign(\dot{\Theta})$. Disturbance matrix is $T_d(\Theta,\dot{\Theta})=\begin{bmatrix}5\sin 5t\\5\cos 5t\end{bmatrix}N\cdot m$.

The desired trajectories are $\theta_1^d(t)=0.5(\cos 3\pi t+\cos 4\pi t),\theta_2^d(t)=0.5(\sin \pi t+\cos 3\pi t)$.

Initial conditions: $\theta_1(0)=1rad,\theta_2(0)=0.5rad$, $\dot{\theta}_1(0)=\dot{\theta}_2(0)=0rad/s$.

The sampling period is 0.0005s and the simulation time is 1s.The simulation language uses MATLAB and the results are shown in Fig.3–6.

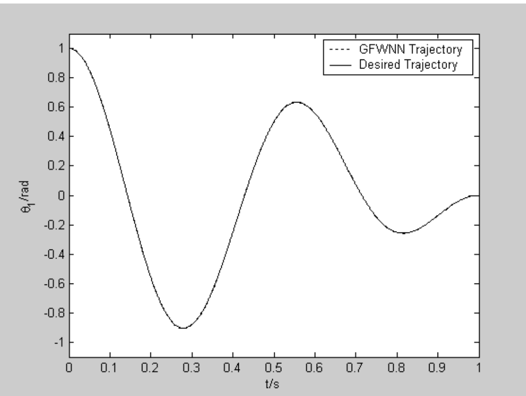

Fig.3. Tracking curve of link 1

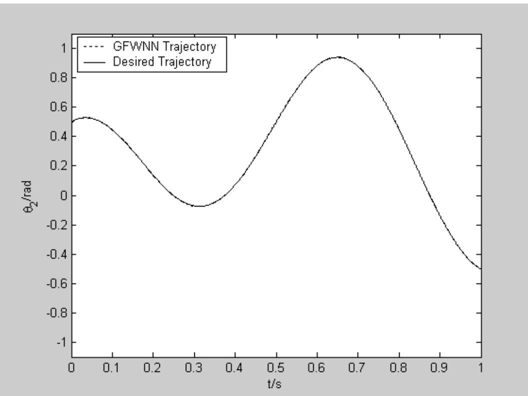

Fig. 4. Tracking curve of link 2

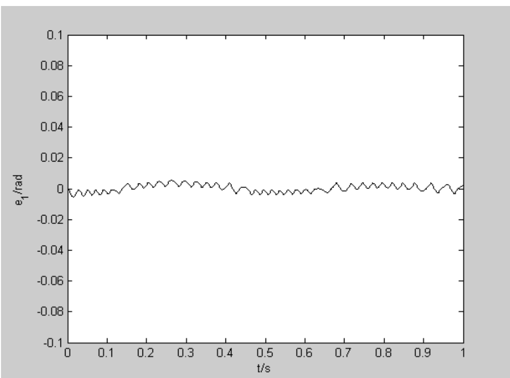

Fig.5. Tracking error of link 1

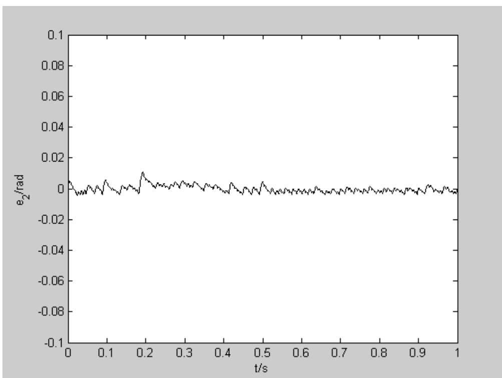

Fig. 6. Tracking error of link 2

Conclusions

In this paper we present a method to obtain the parameters of FWNN controller by GA, which combines the advantages of GA, fuzzy control, neural network and wavelet transform theory. The method is applied to trajectory tracking control of 2-link manipulator. Simulation results show the effectiveness of the proposed method. The method is easily applied to the other controlled objects.

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