RESEARCH ON THE INTELLIGENT CONTROL ALGORITHM FOR A SOFT JOINT ACTUATED BY MCKIBBEN MUSCLES

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Abstract: In view of certain McKibben muscle model and the joint model which actuated by it,we design effective compound control algorithm which based on the CMAC neural network and the PID. The PID controller is to realize the feedback control in order to guarantee system's stability. And the CMAC function forward feed compensator realizes system's counter dynamic model, the parallel controller's output takes system's control action.Through the CMAC learning process so that the PID output tends to zero, making thereby systematic, control action comes into being from CMAC.Digital simulation's result had proven this parallel algorithm has the very high track capacity and the interference immunity, and robustness is strong and the response speed is quick, suits in the nonlinear real-time control.

Key word: McKibben muscle, neural network, CMAC, PID, Control algorithm.

1 Introduction

The Mckibben muscle is one kind of relatively new-style drive. It is one kind of the movement engine which is drived by the barometric pressure may contract. The major characteristic of it is light and supple, meanwhile it can produce enough strength. Because of the similarity with the biological muscle, when it is used in the robot, the robot is easy to produce animal-like movement. Because of its inborn flexibility, this kind of robot, when with environment alternately, it is easy to produce gentle touching and relative security operation, therefore in area of industry assembly, spray coating, capture brittle goods and so on, it has the latent huge application value[1].

At present, the anti-outside disturbance ability of PID control method which is widely used in robot joint controls is bad, and the adaptiveness to system's design parameter change is not good, too. It also affects control system's robustness. However,the development of robot system reqires the robot control to have the fast track capacity, high tracking accuracy and fine robustness. This article uses the CMAC neural network and the PID compound control algorithm。It can fully reflect feature of CMAC that are reducing output errors, good real time performance and strong robusticity in order to control the movement of joint effectively.

2 The McKibben muscle model and the joint model

2.1 McKibben muscle synopsis

The McKibben muscle was invented by American Dr. McKibben in the 1950s which is one kind of the pneumatic driving artificial muscle. Its main body is composed by an expandable rubber pipe of inner layer and the outer layer is of fabric shell constituted by textile fiber, the both sides of the shell and the both sides of rubber pipe both continually in together (Fig. 1). After McKibben muscle has sufficient pressure, the rubber tube starts to expand, as a result of the fibrous layer to the rubber tube movement's restraint, the rubber tube's radial direction expansive power is transformed to the McKibben muscle axial shrinkage force. Thus causes the McKibben muscle to have the radial swelling movement and the axial contractive motion[1]. In the contraction process, its pulling force reduces gradually, enables the McKibben muscle to be able to finally achieve the expectation position. Its shrinkage character is similar to animal's muscle contracture. Afterward, people research and develope and the pneumatic driving artificial muscle one after another, like Japan, some company produced Rubbertuator, some British company produced Air Musule and so on, all take the McKibben muscle as the primary form, and is applied in the industrial field, sometimes it is generally called the McKibben muscle.

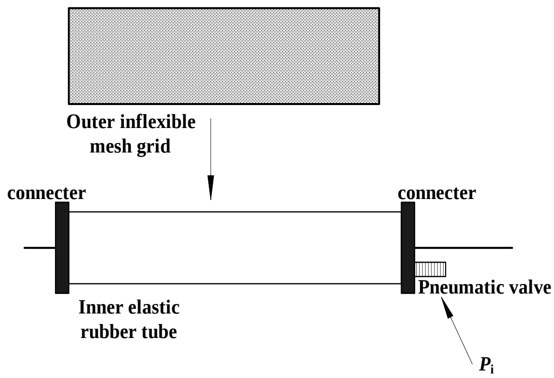

Fig.1 Structure model of McKibben muscle

2.2 McKibben muscle's mathematical model

As an artificial muscle, the shrinkage must be its important concept,.Generally the literature pointed out that its greatest shrinkage is 20%~40%. It is defined as

$$R_c = (L_0 - L)/L_0 \times 100\% \tag{1}$$

And, R_c is the shrinkage, L is the current length, L_0 is the initial length.

Regards the McKibben muscle as the ideal circular cylinder, establishes its geometric model, as shown in Fig. 2. Here we have neglected the non-column shapes of the two sides of muscle, and thought that the internal aerocyst wall thickness is small enough. L is the current length of circular cylinder, D is the current diameter, n is the outer layer textile fiber winding turn, b is the simple root textile fiber length. θ is the outer layer trace angle of bank. When muscle bearing radial swelling, θ increases, L reduces, but b maintains invariable. By now pulling force F is:

$$F = Pb^2(3L^2/b^2 - 1)/(4\pi n^2) \tag{2}$$

Formula (2) is the McKibben muscle's theory strength - length characteristic. After having the barometric pressure inputs, the strength output and the barometric pressure value are proportional, becomes the misalignment relations with the length, in addition concerns with the design parameter.

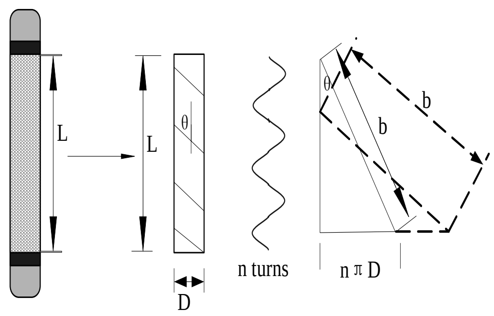

Fig.2 Mathematical model of McKibben muscle

2.3 The Joint actuated by the McKibben muscle

Shown in Fig. 3 for the symmetrical arrangement of two McKibben muscle joint schematic drawing. When the joint is at the initial state of equilibrium, two muscles have same shrinkage R_c and initial intensity of pressure P_0. Records R is the joint transfers the column radius, $F1$ and $F2$ represent pulling force produced by the two McKibben muscles when the joint rotates.When a McKibben muscle's input intensity of pressure change Δp, at the same time another McKibben muscle's input intensity of pressure reverse direction change Δp, transfers an angle ω through the change of McKibben muscle pulling force actuation joint. Then joint static state moment of force.

$$M_s = R(F1 - F2) \tag{3}$$

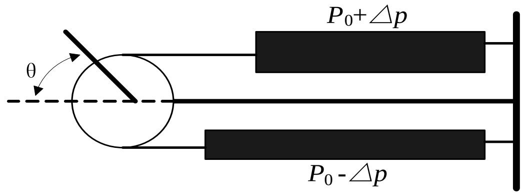

Fig.3 Joint model

Because in the joint rotation process, it is inevitable to introduce joint's dynamic model, namely increases to a speed damping consideration. For different factories, speed damping of different material's product is different. Regarding this joint system, two McKibben muscle resistance establishment actuation joint, two McKibben muscle's speed damping action effect must be more obvious than simple root's function effect, because no matter is the flexure process or stretches out straight in front of oneself the process two muscle's speed damping action effects is superimposes mutually compared to simple root's function effect, and when the contraction speed is big, the speed damping action will be more remarkable, therefore it is the essential consideration to increase the acceleration damping item in the static moment of force foundation. Suppose M_v is the joint angular speed damping item, M_0 is the dynamic moment of force, then:

$$M_0 = M_s - M_v \tag{4}$$

The literature had proven the McKibben muscle's speed damping's existence, through experiments we establish the M_v available equation below expression:

$$M_v = c(P1 + P2)d\omega/dt \tag{5}$$

And c is the speed damping factor, its size is decided by experimental.By the joint dynamic physical model we can know:

$$M_0 = Jd^2\omega/dt^2 \tag{6}$$

And J is the rotor inertia, suppose joint transfers the column for the circle columnar, then:

$$J = \int r^2 dm \tag{7}$$

By take the above equation (3) - (7) we can konw joint's dynamic mathematical model is:

$$J \cdot d^2\omega / dt^2 = R(F1 - F2) - c(P1 + P2)d\omega / dt \tag{8}$$

3 Cerebellum model joint controller neural network (CMAC)

Cereballar Model Articulation Controller is proposed by J.S.Albus in 1975.The simple CMAC principle structural model is shown in Fig. 4, it is constituted by the network input, the concept mapping, the physical mapping and the network outputs[2,3].

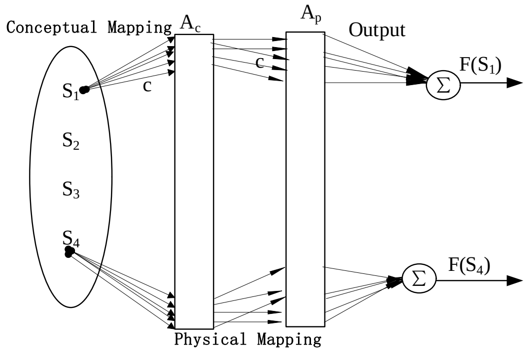

Fig 4 CMAC model

In Fig. 4, A_c is the concept memory cell, A_p is physics memory cell, $F(S_i)$ is the CMAC neural network output. In input state space, each spot in S corresponds to c unit in the concept storage space A_c, also corresponds to c memory cell in the actual storage space A_p, but neural network's output $F(S_i)$ is the sum in these c unit value saves(network weight).

CMAC uses the following learning algorithm: uses δ to study rule adjustment weight, the weight adjustment target:

$$E = \frac{1}{2c} e^2(t) \tag{9}$$

In the formula, $e(t) = r(t) - y(t)$ is according to gradient descent method. Weight adjustment is as follows:

$$\Delta w_j = -\eta \frac{\partial E}{\partial w} = \eta \frac{r(t) - y(t)}{c} \cdot \frac{\partial y}{\partial w} = \eta \frac{e(t)}{c} \tag{10}$$

$$w_j(t) = w_j(t-1) + \Delta w_j(t) + \alpha(w_j(t-1) - w_j(t-2)) \tag{11}$$

In the formula, α is the inertial coefficient.

4 CMAC and PID compound control algorithm

CMAC and PID compound control structure is shown in Fig. 5:

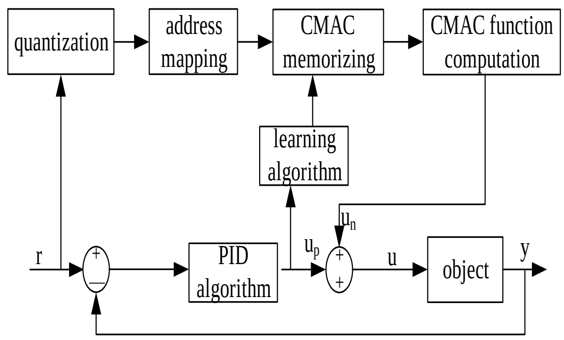

Fig 5 Compound control structure

This system realizes the forward feed reaction control through CMAC and the PID compound control, its characteristic is:

(1) The cerebellum model nerve controller realizes the feed-forward control, realizes the controlled plant counter dynamic model;

(2) The conventional controller realizes the reaction control, guarantee system's stability, and suppresses the perturbation. the this system's control algorithm is:

$$u_n(k) = \sum_{i=1}^{c} w_i a_i \tag{12}$$

$$u(k) = u_n(k) + u_p(k) \tag{13}$$

In the formula, a_i is the binary choice vector, c is the CMAC network pan-parameter, $u_n(k)$ is the corresponding output which CMAC produces, $u_p(k)$ is the output which conventional controller PID produces.

The CMAC adjustment target is:

$$E(k) = \frac{1}{2}(u(k) - u_n(k))^2 \cdot \frac{a_i}{c} \tag{14}$$

$$\Delta w(k) = \eta \frac{u(k) - u_n(k)}{c} a_i = \eta \frac{u_p(k)}{c} a_i \tag{15}$$

$$w(k) = w(k-1) + \Delta w(k) - \alpha(w(k) - w(k-1)) \tag{16}$$

In the formula, η for the speed of network study , $\eta \in (0,1)$, α is the inertia quantity, $\alpha \in (0,1)$.

5 The pneumatic joint's compound control simulation testing

System mathematical model is given in the formula (8):

$$J \cdot d^2\omega / dt^2 = R(F1 - F2) - c(P1 + P2)d\omega / dt \qquad (17)$$

Input is unit step signal. PID controller's parameters are: $K_p = 99, K_i = 0, K_d = 0.75$. Sampling time $t_s = 0.001$. Add disturbance at $t = 0.15$ s.Program and simulate under MATLAB. Output curves of PD controller, CMAC neural network controller and parallel controller are shown in Fig 6.

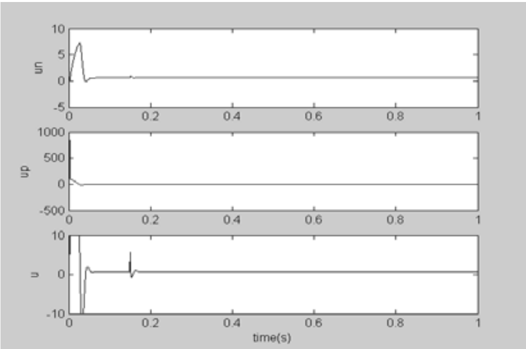

Fig 6 Output curves

We see through the simulation result that: the PD controller has an effect at first,then CMAC controller unceasing study from the outputs of the PD controller and gradually in stead of PD controller .CMAC makes the result of control much better than only use PID . This method realized the feedback control by using traditional PID controller and realized the feed forward control by using CMAC neural network to increase the response speed and control precision.

After added disturbance, the system which is under the disturbance will quickly returen to stable state due to CMAC. CMAC and PID parallel controller can overcome some disadvantages which the PID controller cannot avoid to some extent and improve the effect of controlling.

The Fig.7 and Fig.8 show that CMAC and PID parallel controller can ruduce overshoot of system, Speed up the control response speed and fully reflect feature of CMAC, namely, reducing output errors, good real time performance and strong robusticity.

6 **Conclusion**

In view of complex the mathematical model of which a soft joint actuated by McKibben muscles. This article uses CMAC and the PID parallel controller .Compared with traditional PID or the neural network control method, CMAC and the PID parallel controller has great adaptability and easy to realize.The simulation result proof that this algorithm has the very big enhancement in the control quality and display the very good performance in dynamic response speed, stability and adaptability.

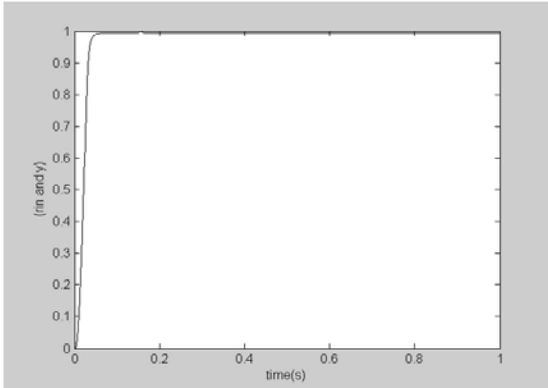

Fig.7 Unit step response curve of CMAC and PID parallel controller

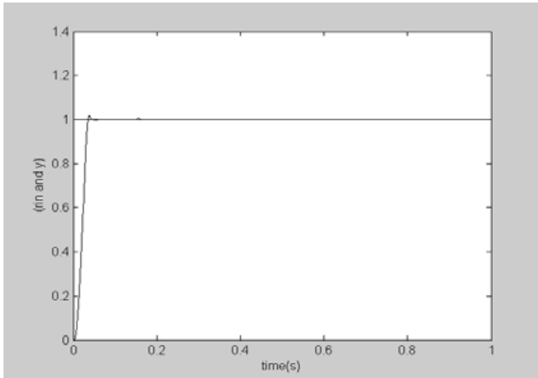

Fig.8 Unit step response curve of only PID controller

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