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Parameter Optimization of PID Controller Based on PSO for Multi-leaf Collimator

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Abstract

According to the control requirements of the leaves' position precision in the multi-leaf collimator, the structure and working principle of the multi-leaf collimator in the conformal radiation therapy apparatus are described. The motor that drives the leaf of the MLC is taken as the control object. The module of the motor has been established. Then the PSO algorithm is used for the parameter optimization of PID controller that outputs the given expectation to the motor, in order to ensure the position accuracy of the MLC leaves. The experimental results indicate that this algorithm can meet the needs of the control precision of the leaves' position of the multi-leaf collimator, and each control index is obviously superior to the traditional method for PID control.

Key words: *particle swarm optimization, multi-leaf collimator, parameter optimization, PID controller, radiation therapy*

1. Introduction

With the deeply research on radiotherapy, the development of equipment for radiotherapy has been improved. Then it is very important to precisely locate on the tumor and adjust the radiation dose [1]. The purpose of the Multi-leaf Collimator(MLC) is to realize the conformal radiotherapy [2]. So, the research of the position of the leaves of the MLC has much more practical significance.

Because the leaves of the MLC are driven by the motor, the paper takes the motor of the MLC as the controlled object, and selects the PID controller as position controller to meet the position accuracy needs of MLC.

Proportional-Integral-Derivative (PID) control is a kind of control strategy that has been successfully used for many years [3], and now PID controller is still widely used in industry control realm. The system could obtain satisfactory control results, when the control system selects the appropriate parameters of PID controller. So it is very important to optimize the parameters of PID controller. But it is difficult to set the parameters of PID controller. At present the commonly used parameter optimization algorithm [4] are Ziegler Nichols, bacterial colony algorithm, genetic algorithm, artificial fish swarm algorithm, particle swarm optimization [5], etc. This paper presents the design of PID controller based on PSO for the MLC. The control system is modeled in Simulink and the PSO algorithm is implemented in MATLAB. This paper has been organized as follows: In section 2, the work principle of MLC has been described and the motor model of MLC has been established. in section 3, the particle swarm optimization method has been reviewed. In setion 4, the solutions to the design of the PSO-PID controller has been provided. In section 5, the simulation of control system has been done in the paper, and the relevant results has been obtained. The conlusion has been made in section 6.

2. Control System Model of the Multi-Leaf Collimator

The multi-leaf collimator is mainly composed by a plurality of leaves, which are arranged in pairs. In radiation therapy system, the position of MLC leaves will be determined based on the shape of the tumor, and the shape of the rays that pass through the MLC is similar to the projection on the irradiated surface of the tumor. The working principle diagram of MLC is shown in Figure 1.

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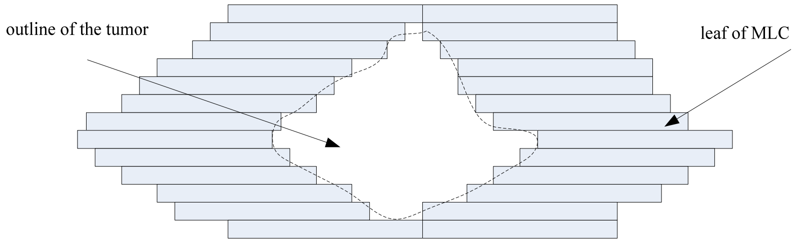

Figure 1. Working principle diagram of MLC

In practical applications, each leaf of MLC is driven by an micro electric motor, and the rotational movement of the motor is converted to a linear motion of the leaf by screw rod. Each leaf has a set of independent controller. The electric motor that has been used in this system includes stepping motor, DC servo motor, and brushless DC motor. The brushless DC motor (BLDC motor) is widely used in MLC control system with many unique advantages [6]. The structure diagram of the close-loop position control system is shown in Figure 2.

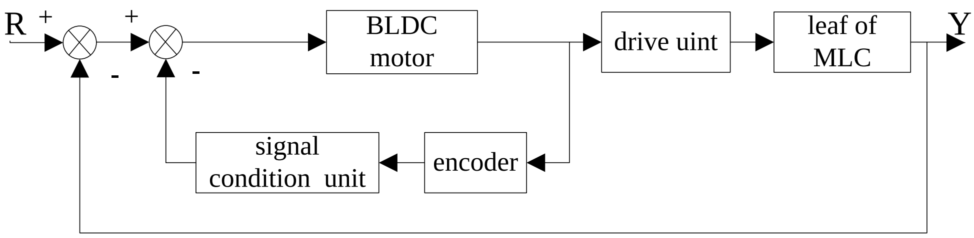

Figure 2. Structure diagram of the close-loop position control system

The following methods have been used for the position accuracy of the MLC leaves. Firstly, the velocity, accelerator and the number of turns or step of motor must be controlled precisely, in order to meet the requirements of the position accuracy of leaves. In this session, the encoder is used to detect the running state of motor. Secondly, the position of leaves has been detected directly to conclude the next running requirements of the motor, and the common method is using a two-dimensional ion chamber array to verify the position of MLC [7].

The paper has made much research only on the control of the motor. The BLDC motor can be controlled precisely by the drive file of MLC outputted from the radiation treatment planning system. The characteristic equations of BLDC motors can be represented as [8]:

$$v_{\text{app}}(t) = L\frac{di(t)}{dt} + Ri(t) + v_{\text{emf}}(t) \tag{1}$$

$$v_{\text{emf}} = K_{\text{b}}\omega(t) \tag{2}$$

$$T(t) = K_{\text{t}}i(t) \tag{3}$$

$$T(t) = J\frac{d\omega(t)}{dt} + D\omega(t) \tag{4}$$

where v_{app} is the applied voltage, $\omega(t)$ is the motor speed, L is the inductance of the stator, $i(t)$ is the current of the circuit, R is the resistance of the stator, v_{emf} is the back electromotive force, T is the torque of motor, D is the viscous coefficient, J is the moment of inertia, K_t is the motor torque constant, and K_b is the back electromotive force constant. From the characteristic equations of BLDC motor, the transfer function of speed model is obtained as formula (5), and the diagram of BLDC [9,10] motor is shown in Figure 3.

$$G(s)=\frac{Y(s)}{R(s)}=\frac{K_t}{LJs^2+(LD+RJ)s+K_\mathrm{t}K_\mathrm{b}} \tag{5}$$

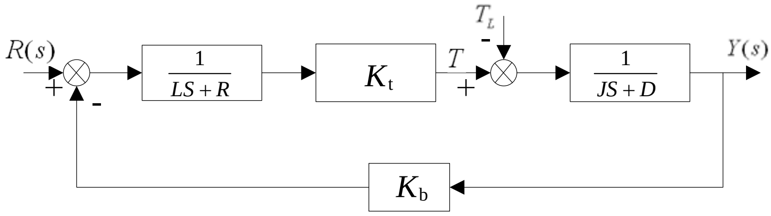

Figure 3. The diagram of BLDC motor

The parameters of the motor used for simulation are as follows:

K_t is the motor torque constant: $3.08\times10^{-3} N\cdot m/A$;

K_b is the back electromotive force constant: 0.0294;

L is the inductance of the stator: $0.035mH$;

J is the moment of inertia: $0.75gcm^2$;

R is the resistance of the stator: 1.26Ω;

D is the viscous coefficient: 7.14×10^{-5}.

3. Review of PSO Algorithm

Particle Swarm Optimization(PSO) is a evolutionary computation technique presented by Kennedy and Eberhart in1995 [11]. With the original idea coming from the social behavior of biology in nature, such as flocks of birds and schools of fish.

In PSO algorithm [12,13], each particle in swarm represents a solution to the problem and it is defined with its position and velocity, the mathematical description of the basic particle swarm optimization is as follows.

Supposed the scale of swam is N , the position of particle i can be expressed as:

$$x_i=(x_{i1},x_{i2},\cdots,x_{iD}) \tag{6}$$

The velocity of particle is defined as the distance of particle movement in each iteration, described as formula (7).

$$v_i=(v_{i1},v_{i2},\cdots,v_{iD}) \tag{7}$$

And the velocity of the particle $i(i=1,2,\cdots,N)$ in the $d(d=1,2,\cdots,D)$ -dimensional space which is adjusted according to formula (8) is:

$$v_{id}=v_{id}+c_1rand_1()(p_{id}-x_{id})+c_2rand_2()(p_{gd}-x_{id})$$

$$\begin{cases} v_{id} = v_{\max}, & if \quad v_{id} > v_{\max} \\ v_{id} = -v_{\max}, & if \quad v_{id} < -v_{\max} \end{cases} \tag{8}$$

Finally, the particle can adjust its position according to formula (9) is:

$$x_{id} = x_{id} + v_{id} \tag{9}$$

where N is the number of particles in the group, d is the dimension, v_{id} is the velocity of particle i, c_1 and c_2 is the acceleration constant, $rand()$ is the random number between 0 and 1, x_{id} is the current position of particle i, p_{id} is the best previous position of the ith particle, p_{gd} is the best particle among all the particles in the population.

4. Design of PSO-PID controller

4.1. PSO-PID controller

The structure diagram of PID control system based on PSO is shown in Figure.4.

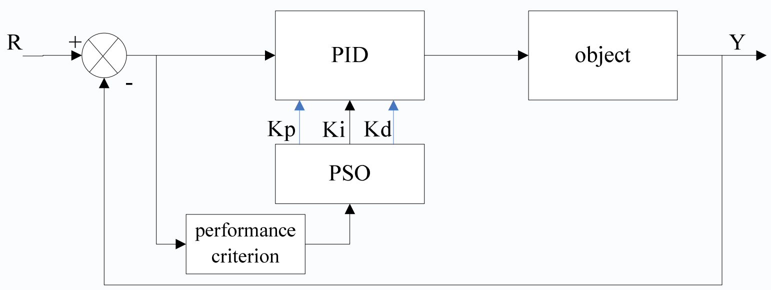

Figure 4. Structure diagram of PID control system based on PSO

This controller is designed mainly for the following two components: the PID controller for the object and the module of the PSO algorithm.

According to the operating state of the system, the module of PSO can optimize the parameters of the PID controller to meet the performance requirements, and the output of this module will provide the optimized parameter of PID controller.

And now, the most common performance criteria in PID controller are described as follow:

(1) integrated of time weight square error:

$$ITSE: J = \int_0^{\infty} t^2 e^2(t)dt \tag{10}$$

(2) the integral of time multiplied by absolute error:

$$IATE: J = \int_0^{\infty} |e(t)tdt| \tag{11}$$

(3) integrated of squared error:

$$ISE: J = \int_0^{\infty} e^2(t)dt \tag{12}$$

(4) integrated absolute error:

$$IAE: J=\int_0^{\infty}|e(t)|dt \tag{13}$$

The IATE is selected as the performance criteria of this PSO-PID controller in the paper.

4.2. Implementation of PSO-PID Controller

The implementation steps of parameter optimization of PID controller based on PSO can be divided as follow:

step1: Generate initial Population;

step2: To determine the fitness value of each particle using the performance criteria;

step3: To analyses the fitness value of each particle, and update the global optimum position value;

step4: To update the velocity and position of the particle;

step5: If the maximum iteration number comes to the end or the performance criteria is satisfactory, the system gets the optimal solution. Otherwise, it returns to step 2.

The specific method:

1. Initialize the number of the particle(Population size): Population size affects the performance of the PSO algorithm. It is easy to get local optimal solution, if the population size is small. If the population size is too large, it is difficult and time-consuming to realize, which will exponentially increase the complexity of the algorithm. In this paper, the population size is set to 50.

2. Initialize the particle dimension: the number of the particle dimension is determined by the optimized object. The output of the PSO module are the three parameters of PID controller, such as K_{p} , K_{i} and K_{d} , so the particle dimension is set to 3.

3. Initialize the range of particles: in order to accelerate the calculation speed, the PID parameters have been adjusted by Ziegler-Nichols with trial and error firstly in the paper. Then these three parameters are set to $K_{\mathrm{p}} \in [0,300]$, $K_{\mathrm{i}} \in [0,3]$, and $K_{\mathrm{d}} \in [0,6]$.

4. Determine the fitness value: calculate the fitness value of each particle through the integral of time multiplied by absolute error, $IATE: J=\int_0^{\infty}|e(t)|tdt$.

Finally, In this work, the initial value of the particles are randomly generated within a certain space. The other parameters are chosen as follows: ω (Inertia weight factor)=0.6; c_1 and c_2 =2; $v_{\max}$ =1, $v_{\min}$ =-1;Iteration =10.

5. Simulation and Results

In this section, the simulation module diagram of PID controller that has been established through MATLAB simulink toolbox is shown in Figure.5.

At first, the PSO program module passes the initial value of the particles to the simulink module by calling the sim, assignin or evalin function. Then, the simulink module calculates the fitness value that based on the performance criteria: IATE and outputs it to the PSO program module. So the cycle to repeat, until the maximum iteration number comes to the end or the performance criteria is satisfactory.

The design takes the step signal as input signal to achieve the step response of the control system, which is shown in fig.4. The curves of the global optimal fitness value is shown in Figure 6 and the curves of the PID parameters are shown in Figure 7, Figure 8 and Figure 9.

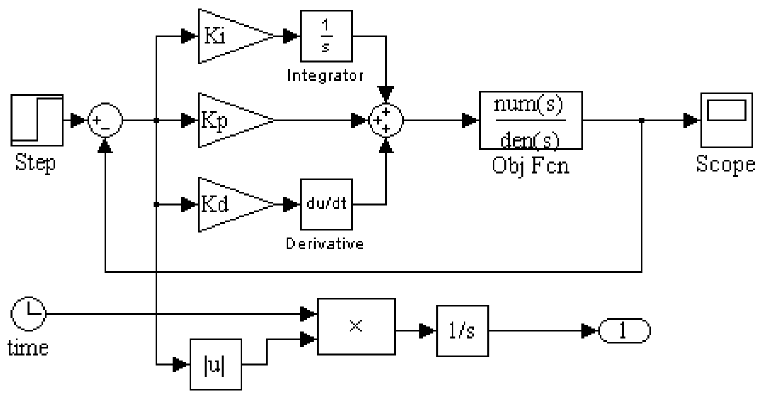

Figure 5. Simulation diagram of PID controller

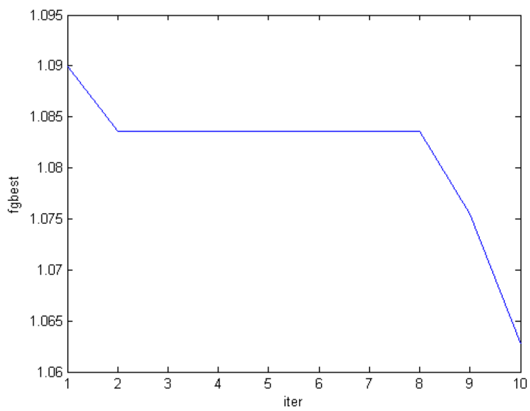

Figure 6. Curve of the global optimal fitness value

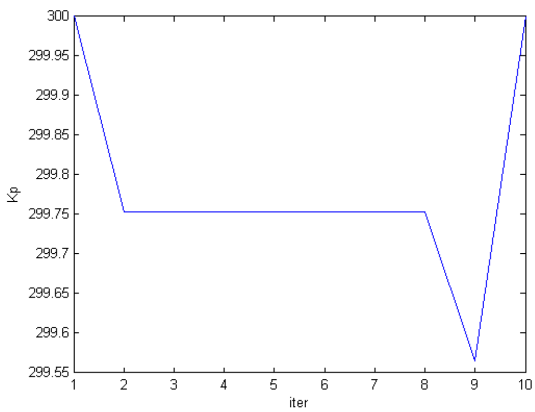

Figure 7. Curve of the K_p based on PSO

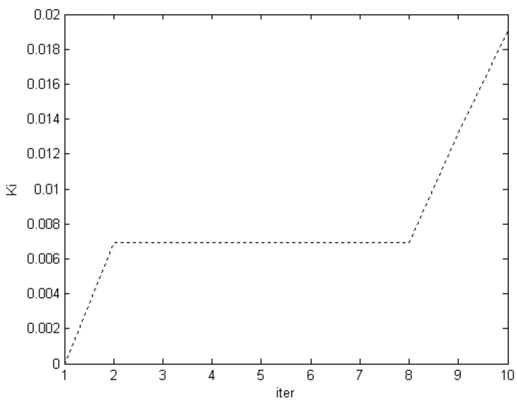

Figure 8. Curve of the K_i based on PSO

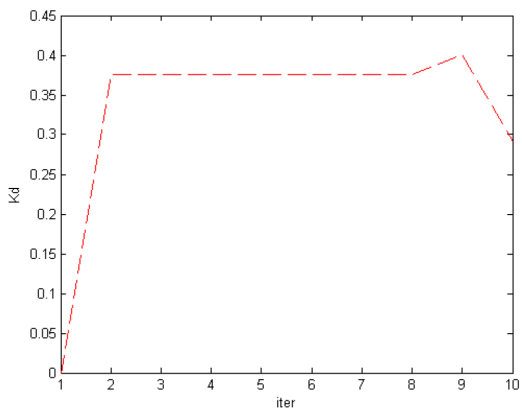

Figure 9. Curve of the K_d based on PSO

Another two examples of the fuzzy adaptive algorithm and Ziegler-Nichols with trial and error for PID controller is given to illustrate the proposed design is effective. The results of the three methods are shown in Figure 10.

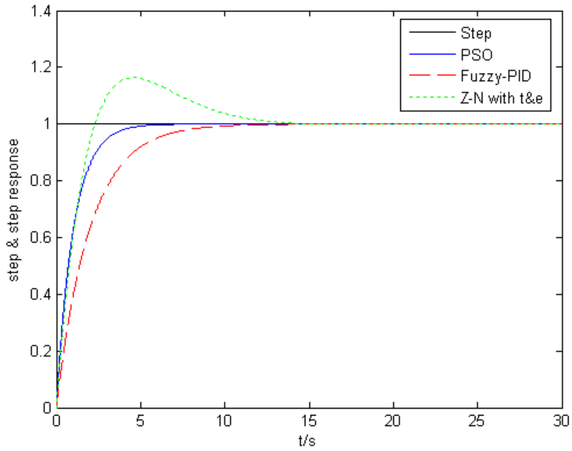

Figure 10. Step response curve of output with the three control strategies

The results of the simulation show that the output curve of the proposed method in the paper has the fastest settling time without overshoot. The settling time of Z-N PID control is slowest, and the overshoot of Z-N PID control is biggest. The fuzzy adaptive PID has no overshoot, but the response time of the fuzzy adaptive PID is slower than that of the proposed method in the paper. In conclusion, the performance index of the proposed method is better than that by using the fuzzy adaptive PID algorithm and the Ziegler-Nichols.

6. Conclusion

Particle Swarm algorithm is a robust, simple and very efficient optimization algorithm. In this paper, the PSO-PID controller is designed for the motor of the MLC. The paper explains how to optimize the parameter of PID controller based on the PSO algorithm. The research and simulation results show that the optimized PID controller parameters based on PSO algorithm can obtain the satisfactory control effects; the method is versatile, effective and feasible. It overcomes the shortcomings of the PID controller parameter tuning difficulties. The result indicates that the motor can stably run according to the MLC drive file that is outputted by the radiation treatment planning system, so that the leaves can reach the assigned position accurately.

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