Journal of Computational Science & Engineering 10 (2014) 406-412

Journal of Computational Science & Engineering

Available at http://www.asocse.org ISSN 1710-4068

Research for Control Parameters Optimization of 6-DOF Flight Simulator Based on Particle Swarm Optimization

[1]Kai Zhou , [1, 2]Yun Lu*, [1]Weijia Li , [1]Xiao Wang

[1]*School of Naval Architecture and Ocean Engineering, Huazhong University of Science and Technology, Wuhan, 430074, Hubei China*
[2]*Detachment of Warship Training, Dalian Naval Academy, Dalian, 11618, Liaoning China*

Article Information

Article history:
Received 10 December 2013
Revised 25 January 2014
Accepted 28 January 2014
Available online 29 January 2014

Keywords:
AC servo motor drivers
Controlling parameter optimization
Particle Swarm Optimization
Stewart platform
Roulette operator

Abstract

Based on a 6-DOF flight simulator driven by electricity, the experiments show that certain parameters of the AC servo driver have a great impact on the stability of the platform. The study of the optimization for controlling parameters of the AC servo drivers is carried out by the continuous change to the controlling parameters, aiming to improve the performances of the platform in stabilization and frequency response by Particle Swarm Optimization. The result shows that the Particle Swarm optimization algorithm is fitted for the system of the controlling parameter optimization.

1. Introduction

The flight simulator provides realistic flight environment for pilot training by simulating the space 6-DOF motion. Compared with the traditional training, it can save training expenses, and also fully guarantee the safety of pilots. Therefore, the flight simulator is used to train pilots more and more. Electric 6-DOF platform is an important component of the flight simulator. The transient overload feel and the dynamic information of attitude angle changes within a certain range are given by the platform. So the stability and frequency response have some strict requirement [1].

The motivation of the platform is provided by the servo motor. The control performance of the AC servo driver which is the kernel control part of the motor system directly affects the performance of the entire platform system. However, there is always a contradiction between the speed of response and stability of the system. So the

* Corresponding author: hustluyun@hust.edu.cn

2014 © The American Computational Science Society. All rights reserved.

appropriate controlling parameters are selected to make a compromise between the speed of response and stability. In this paper, the controlling parameter optimization based on Particle Swarm Optimization effectively solves the contradiction between the speed of response and stability of the system.

2. Structure of the Platform && the Control Theory Analysis

The research object of this paper is based on the structure of Stewart platform that simulates the space 6-DOF motion. The platform consists of six electric cylinders, the upper platform(motion platform),the lower platform(fixed platform) and cross hinge(connecting the upper and lower platforms with the electric cylinders).It is shown in figure 1.The upper and lower platforms are connected in parallel with electric servo cylinders by the cross hinges so that the six electric servo cylinders can flex independently [2].Through the coordinate flexing of cylinders, the spatial position and attitude on the six freedom can be achieved. The electric cylinder is driven by the AC servo motor which has a working stroke of 860mm, output force 28KN and achieves the maximum speed of 600mm/s. Each set of the cylinder is driven by a AC servo motor and a corresponding driver. The motor that is the brushless servo motor of Fissler ultract Ⅲ series has a rated power of 6.7kW.And the driver is LENZE 9400H series.

The motion control of the platform is based on position control. The communication of the input control instruction between host computer and the servo drivers is achieved by the CAN bus. According to the servo driver control instruction and the feedback signal of servo motor encoder, the closed loop control is realized by the internal adjustment of the driver. The optimization research of the control system is carried out based on the sinusoidal signal input. The control effect is evaluated through the feedback state information of the control system which is sent by the CAN bus communication. The corresponding control parameters of the driver gotten by the optimization algorithm can be set through RS232 serial port. The control system schematic is illustrated in figure 2.

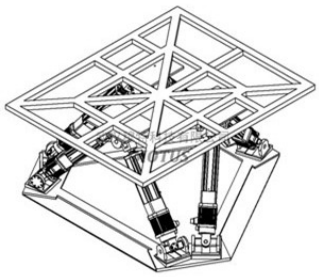

Fig. 1 6-DOF motion platform

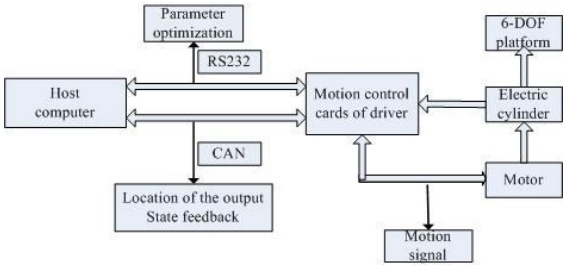

Fig. 2 control system schematic

3. Analysis for the Optimization Model of Control System Parameters

3.1 The selection of optimization parameters

In theory considering the approximate linear relationship between the acceleration of the platform and the current of the servo driver, therefore the drive current directly affects the frequency response and stability of the electric cylinder. So in this paper, the drive current of the servo motor is selected as the research object. The response and motion stability of each cylinder are made to be comprehensive optimal by improving the control quality of the drive current. Accordingly, the control effect of the whole platform is also overall optimal.

A great deal of experiments show that there are four control parameters in each control loop which have significant influence on the performance of the servo motor for the position control. The parameters are speed loop gain,

2014 © The American Computational Science Society. All rights reserved.

integral time constant of speed loop, current loop gain and integral time constant of current loop. The four main control parameters above are selected as independent variables for optimization. With the typical sinusoidal signal input and constraint conditions of the requirements for dynamic characteristic, the disturbance value of drive current is made to be minimum through the optimization algorithm so that the motion platform can get the best performance.

3.2 Optimization mathematical model

(1) The design variables

The design variables of the control system are X which is the parameter for position control: $X=[x1,x2,x3,x4]$

$x1$: Speed loop gain.

$x2$: The integral time constant of speed loop.

$x3$: Current loop gain.

$x4$: The integral time constant of current loop.

(2) Objective function

The drive current of servo motor is selected as the research object through the analysis above. So the objective function of the system parameter optimization is as follows.

$$\min[f(x)]=\lambda_1\cdot g_1(x)+\lambda_2\cdot g_2(x) \quad (1)$$

$$g_1(x)=\Delta I \quad (2)$$

$$g_2(x)=\Delta i_{A-A} \quad (3)$$

$g_1(x)$ is the reverse performance indicator of the electric cylinder which is decided by the mutation of the reverse current. The smaller ΔI is the more stable the reverse current is. Then the better the performance of the reversing is. $g_2(x)$ is the motion performance indicator which is decided by the peak-to-peak value of the current disturbance in the process of movement. The smaller Δi_{A-A} is, the more stable the movement of electric cylinder is. λ_1 and λ_2 is the weigh coefficients which are set to 0.5 based on the actual design requirements.

(3) Constraint conditions

According to the requirements of the drive performance, the range of control parameters has been limited by manufacturer. But the range is so large that these parameters don't have any practical significance. Therefore, base on the reference for the range provided by manufacturer and a great deal of earlier period experiments, the control parameters are limited in a certain smaller range by factitiously removing the useless data. The constraint conditions of design variables are as follows.

Speed loop gain: $0.04\le x1\le 0.1$

The integral time constant of speed loop: $300\le x2\le 1000$

Current loop gain: $1\le x3\le 50$

The integral time constant of current loop: $2\le x4\le 500$

In the engineering, the sinusoidal signal of 0.5Hz is often selected as the typical evaluation frequency of stability. And with this signal input, the requirements based on GB-2021-94 for the closed loop response of 6-DOF flight simulator are as follows.

Phase lag: $\Delta\varphi\le 15°$

Amplitude attenuation: $\Delta A\le 1.0dB$

3.3 The selection of optimization method

The optimal control parameter design of Motor Servo System is a specific engineering project. The optimized mathematical model, the restrain and objective function have been discussed before. Based on amounts of GA experiments and PSO simulation, three or more improvements are needed to solve the single-objective-function with multivariate, multiple peak value and multi-constraint.

(1) Avoid prematurity: For GA, because of the variance of individual distribution ,population size etc，there will be local convergence problem. The PSO we used in the paper integrates based on the roulette wheel selection operator, make the population memoryless at initial phase to avoid local optimal solution. The prematurity problem is avoided excellently [3].

(2) Rate of convergence: PSO has perfect

2014 © The American Computational Science Society. All rights reserved.

memorability on global optimal solution. Each generation of particles through self-learning and social-learnling, utilize the inertance of themselves at the same time, particles move to global optimal solution more quickly. So the rate of convergence of PSO is faster than GA's.

(3) Optimal solution available: Upon the acquisition of solution, GA gets into prematurity easily, and the solution is quasi-optimal, not the best. Where as the PSO can make global optimal solution available.

For the three aspects, PSO is selected to optimize the parameter of driver and search the optimal solution.

4. The Realization for Parameters Optimization of PSO Algorithm

The model of parameters optimization has been described above.Next, based on the theory of standard particle Swarm Optimization, several improvements are proposed in this application

4.1 Standard particle swarm optimization

The iterative formula of standard PSO is as follows.

$$V_i(t+1) = \omega V_i(t) + C_1 r_1(P_i(t) - X_i(t)) + C_2 r_2(P_g(t) - X_i(t)) \quad (4)$$

$$X_i(t+1) = X_i(t) + V_i(t+1) \quad (5)$$

$P_i(t)$ is the individual extremum, and $P_g(t)$ is the global extremum.Both C_1 and C_2 are constants which respectively represent the degree of influence by social cognitive knowledge and the particle individual cognition (also known as the learning rate). C_1 and C_2 are usually set to the same value which weight equally. r_1 and r_2 are the random numbers on the interval of (0, 1). As the inertial factor, ω can dynamically adjust the iterative velocity of the particles over time so that the particles can gradually move to the local search.

The standard process of particle swarm algorithm is as follows:

(1) Initialization. Setting the acceleration constants c1 and c2, the biggest evolution generations M and the size of the population, randomly generating initial particles and the particles' velocity in domain, which constitute the matrix of velocity [4].

(2) The individual evaluation (the fitness function); It is used to evaluate the merits of the particles.

(3) For each particle, compare the current fitness value with the current best, if it is better than the latter, use the current fitness value as the current best, otherwise unchanged; For the best fitness value in the population, compare the current best fitness value and the ever best fitness value in the population, so as to get the current extremum of population [5].

(4) Using the formula (4) and (5), respectively update the speed and position of each particle.

(5) If the result meets the termination condition, the program terminates, otherwise turn to (2).

The standard process of particle swarm algorithm is showed in Figure 3.

4.2 The realization of the optimization process

The particle swarm optimization algorithm need to solve the problem of the optimal drive parameter matching. Correspondingly, the following key questions should be solved.

(1) The construction of solution space

The control parameters that are to be optimized in the system have their own ranges. In order to ensure the diversity of particle, a group of numbers within the required interval is constructed randomly [6]. For example, $x_1 \in [0.04, 0.1]$ so the construction of x_1 is described in formula (6).

$$x_1 = 0.04 + random(0,1) \cdot 0.06 \quad (6)$$

Through this method, the initial values are generated randomly which are on the interval of (0, 1).And it also ensures the diversity of particle swarm.

(2) Handling of the constraint condition

In the process of iteration, since the individual

2014 © The American Computational Science Society. All rights reserved.

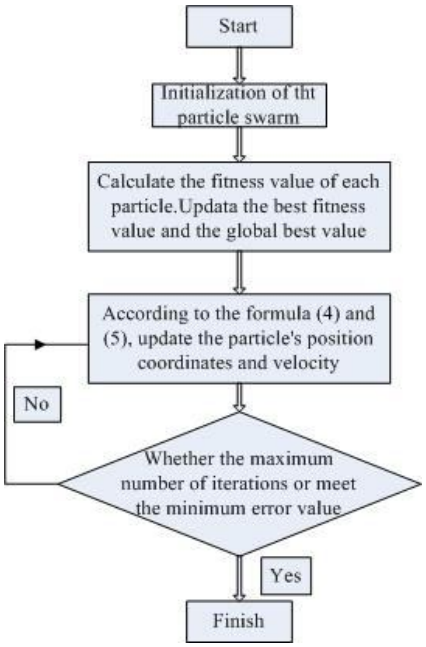

Fig. 3 the standard process of PSO

learning and the adjustment of the particle swarm, and its own inertia, sometimes the motion of particle ranges over the given constraint. The position of particle is needed to be updated. The general processing method is that assigning the boundary position to the current of the particle.

The unsuitable particles are removed by reducing the fitness value through the penalty function. Through this method, the constraints for frequency response are easily handled.

(3) The decision of operating parameters

The operational parameters of particle swarm optimization algorithm mainly include: the size of particle swarm M, terminated generations T, maximum velocity $V_{\max}$, inertia weight factor ω, accelerated factor c1 and c2, etc.Some parameters are decided as follows.

According to the experience, the size of the particle swarm is usually set to 20-40.In the paper is set to 40.And the terminated generations T is set to 50.Generally, the maximum velocity is set to 10%-20% of the interval. In this paper, $V_{\max}$ is 10%.If the current velocity is bigger than the maximum, the current velocity is updated to the maximum. Inertia weight factor ω is 0.8 which describes the flight direction of particles. Considering that the accelerated factor is often set to 2-4, both c1 and c2 are set to 2 which respectively describe the weight of self-learning based on the individual memory and the weight of self-learning and relationship between the particles.

(4) The selection of fitness function

For the fitness calculation of each particle, considering that the value of objective function must be greater than zero based on the formula (1), and it belongs to the problem of searching the minimum value. Therefore, the fitness function is set as shown in following formula (7).

$$fit\{f(\mathrm{x})\} = \frac{1}{1+f(\mathrm{x})} \qquad (7)$$

The objective function value of excellent particle is small.Correspondingly; its fitness function value is large which can lead particle motion to the optimal solution.

(5) Hybrid particle swarm optimization algorithm based on roulette operator

As the iterative process in the early, search process tend to be controlled by a few super-particle whose fitness has the absolute advantage, if the problem of the objective function is multimodal, from a long-term perspective, such particles are not able to boot populations to the global optimum direction, so it is likely to cause the problem of premature convergence [7]. This article uses the objective function roulette selection, make the initial optimal individual selected as global extreme Pg with a smaller probability, after calculating the results of objective functions of all particles randomly selected by roulette operator as Pg, the probability of particle i selected is:

$$P[\mathrm{i}] = \sum_{j}^{i} q[\mathrm{j}] \qquad (8)$$

$$q[\mathrm{i}] = \frac{f(\mathrm{xi})}{\sum_{j=1}^{M} f(\mathrm{x})} \qquad (9)$$

2014 © The American Computational Science Society. All rights reserved.

4.3 Analysis of optimization results

As the selected optimization method and the operating parameters, the servo drive parameters are matched based on the particle swarm optimization. The optimization results are as follows.

(1) The distribution of the fitness function values of the particle for the initial particle group is showed in Figure 4.

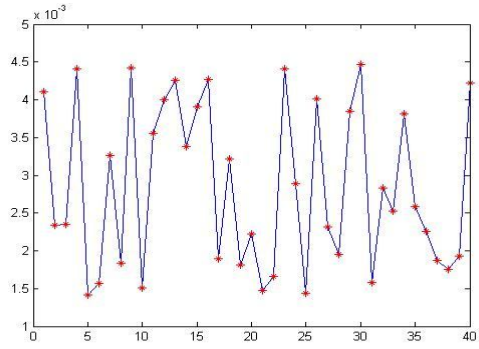

Fig. 4 distribution of the fitness function values for the initial particle group

(2) The distribution of fitness function values of the particle after 20 iterations is showed in Figure 5.

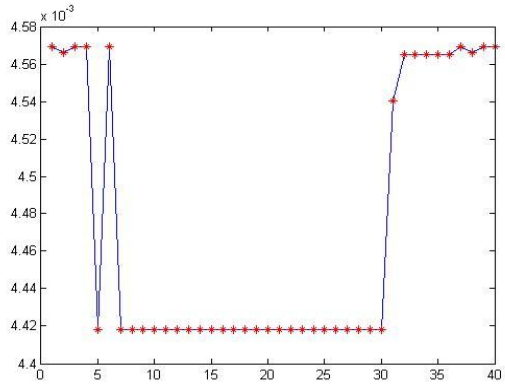

Fig. 5 The distribution after 20 iterations

(3) The distribution of fitness function values of particles after 50 iterations is showed in Figure 6.

(4) The distribution of the fitness function value for the optimal solution in the process of 50 iterations is illustrated in figure.7

The experiments show that the distribution of the fitness function value for the initial particles is dispersive and high random that means the diversity of particle swarm which is good for searching the optimal solution in figure 4. As

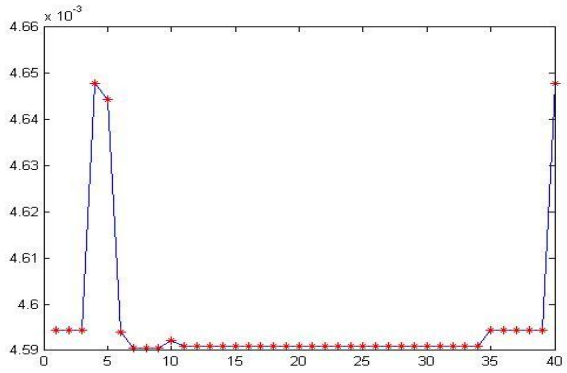

Fig. 6 The distribution after 50 iterations

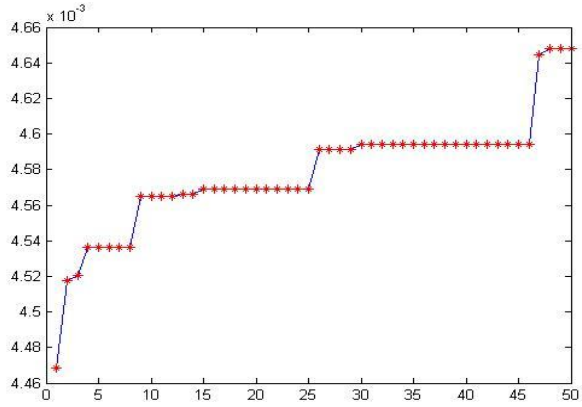

Fig. 7 The distribution for the optimal solution

shown in figure 5 and 6, the fitness function value of particle swarm tends to unity after 20 iterations. But there are still a small portion of the particles in local solution space. The fitness function value converges better and tends to be more stability basically after 50 iterations. Above all, particle swarm optimization algorithm has a good effect on solving the problem of parameter matching.

4.4 Experiment results

The final optimization results of the control parameters are shown in table 1 based on the analysis and experiments.

Table 1 The optimization results

Control parameters	X1/ (Nm/rpm)	X2/ (ms)	X3/ (V/A)	X4/ (ms)
Initial solution	0.07	400	20	35
optimal solution	0.048	465	14	220

5. Conclusions

2014 © The American Computational Science Society. All rights reserved.

Through repeated verification and the early experiment data, the experiment results show that hybrid particle swarm optimization algorithm based on roulette operator has better adaptability for the optimization of the drive control parameters, and well solves the contradiction between the stability and the rapidity of platform.

References

[1] W.B. Luo, Research and Implementation of the Three Degrees of Freedom Motion Platform,WuHan: Huazhong university of science and technology library, (2011).

[2] W.J. Li, WuHan: Huazhong Univ. of Sci.&Tech, 25 (1997) 38-40.

[3] J. Long, Iournal of Civil Aviation Flight University of China, 16 (2005) 21-24.

[4] H.I. Shaheen, G.I.Rashed, S.J.Cheng, Engineering Applications of Artifi cial Intelligence, 23 (2010) 203-216.

[5] G.Z. Sun, Optimal design and application, BeiJing: China Communications Press, (2000).

[6] C.H. Sui, Xi An: Southwest Jiaotong University, (2010).

[7] M. Saravanan, S. Mary Raja Slochanal, P. Venkatesh, J. Prince Stephen Abraham, Electric Power Systems Research, 77 (2007) 276-283.

2014 © The American Computational Science Society. All rights reserved.