Identification of fast-steering mirror based on chicken swarm optimization algorithm

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Abstract. According to the transfer function identification method of fast steering mirror exists problems which estimate the initial value is complicated in the process of using, put forward using chicken swarm algorithm to simplify the identification operation, reducing the workload of identification. Moreover, chicken swarm algorithm is a meta heuristic intelligent population algorithm, which shows global convergence is efficient in the identification experiment, and the convergence speed is fast. The convergence precision is also high. Especially there are many parameters are needed to identify in the transfer function without considering the parameters estimation problem. Therefore, compared with the traditional identification methods, the proposed approach is more convenient, and greatly achieves the intelligent design of fast steering mirror control system in engineering application, shorten time of controller designed.

1 Introduction

The controller design of the fast steering mirror (FSM) is mostly based on frequency domain. The dynamic signal analyser is used to get frequency characteristic and identify the transfer function of FSM. Finally, we can design controller based on openloop transfer function is identified. In order to bring into play potential of FSM and improve satbility and track capability for mesure frequency characteristic, identify transfer function and controller parameter modify should be satisfied with highly precision. However, the existing transfer function identification of the FSM need to estimate the parameters which have complicated problems in the actual operation process, so we should find a simple identification algorithm to overcome this problem. At the same time to ensure accuracy with identification.

There are two types identification methods with openloop transfer function in the FSM. When transfer function model is given, Engineers can rely on experience to adjust the parameters of fitting curve through the reference curve in the Bode diagram and have it been the same as reference curves. But fitting accuracy of transfer function can not be guaranteed and debugging is complicated and time-consuming. Another method is based on the principle of least squares algorithm identify transfer function. Huhaojun get high precision fitting with nonlinear least squares algorithm [1]. But the least squares method must artificial estimate an initial approximation as real value, otherwise, it will fall into the local optimum in the convergence process and lead to solve failure [2]. Therefore the initial value must meet the requirements with approximation of the true value, and the specific implementation is tedious and time-consuming for the manual trial. So a new method which use chicken swarm
optimization algorithm to simplify the system identification operation and improve identification precision is proposed.

2 Identification algorithm

Chicken Swarm Optimization Algorithm (CSO) was proposed by XianbingMen of Shanghai Maritime University in 2014. It is a kind of heuristic optimization algorithm with better convergence accuracy and robustness. Theoretically, it is a global optimization algorithm. The core idea of CSO is that chicken group is divided into multiple groups by the rank order and foraging ability to make sure each group consists of a cock and several hens and chickens, and competitive relation between different groups and different levels of chickens. According to the biological characteristics of chicken, ideally regulating the behavior of each chicken from the aspect of mathematics. It represents the foraging ability of individual chickens. The smaller fitness value means the stronger foraging ability. In general, the rooster has the strongest ability to find food, followed by the hen, chicks have the worst foraging ability [3].

Suppose there are \( N \) virtual chickens in the chicken population. During the \( t \) time, their positions are \( x_{i,j}(t) (i \in [1,...,N], j \in [1,...,N]) \), \( D \) is the spatial dimension of chicken foraging. Cocks, hens and chicks were fed on their respective motion search models.

2.1 Rooster search strategy

The motion behaviors of cock is formulated as (1):

\[
x_{i,j}^{(t+1)} = x_{i,j}^t + \left( 1 + \text{Randn}(0,\sigma^2) \right) (f_i - f_{\text{best}})
\]

\[
\sigma^2 = \begin{cases} 
1, & f_i \leq f_k \\
\frac{f_k - f_i}{|f_j| + \varepsilon}, & \text{otherwise}
\end{cases} 
\]

\( \text{Randn}(0,\sigma^2) \) is the Gauss distribution function which mean value is zero and the standard deviation is \( \sigma^2 \). \( \varepsilon \) is used to avoid zero division error which is the smallest constant in a computer. \( k \) is an index of a rooster by randomly selecting from a group of cocks and \( f \) is the corresponding fitness value of \( x \).

2.2 Hen search strategy

Hens follow their flock of cocks in searching of food. In addition, although the hens will be suppressed by other chickens, they can also randomly steal food which is found by other chickens. So the movement behavior of hens is formulated as (2):

\[
x_{i,j}^{(t+1)} = x_{i,j}^t + S_1 \times \text{Rand}(x_{i,j}^t - x_{i,j}^t)
\]

\[
+ S_2 \times \text{Rand}(x_{i,j}^t - x_{i,j}^t)
\]

\[
S_1 = e^{\frac{f_i-f_j}{10\sigma^2}}
\]

\[
S_2 = e^{f_j-f_i}
\]

Among them, \( \text{Rand} \) is a uniform random number in \([0,1]\). \( r_1 (i \in [1,...,N]) \) is an index of the rooster, which represent No. \( i \) of the hen's group mates, \( r_2 (i \in [1,...,N]) \) is the index of the chicken (cock or hen), which is randomly selected from the group, and \( r_1 \neq r_2 \).

2.3 Chicken search strategy

Chicks are around about their mothers looking for food. Therefore, the movement behavior of chicks is formulated as (3):

\[
x_{i,j}^{(t+1)} = x_{i,j}^t + \text{FL} \times (x_{m,i}^t - x_{i,j}^t)
\]

\( x_{m,i} (m \in [1,N]) \) represents the position of the No. \( i \) chick's mother, and FL(FL \in [0,2]) is a parameter, which means that the chick will follow its mother to find food. Considering individual differences, FL of each chick will be randomly selected between 0 and 2.
2.4 Algorithm flow
Compared to chicken swarm algorithm convergence process, particle swarm algorithm has obvious advantages, its convergence process is divided into 3 steps, firstly using cock search rules to find feasible solution region, and then using the hens and chicks search rules to further optimize and improve the accuracy of the solution.

![Fig. 1 Solve area](image)

Following the below rules shown in Fig. 2, after a certain period of time, according to the current fitness of each chicken, the whole chicken population was redistributed to achieve the update. And then continue to search for the optimal solution depend on the behavior of the chicken.

![Fig. 2 Algorithm flow diagram of the CSO](image)

3 Fast steering mirror model
There is a fast steering mirror with the voice coil motor which is driven as the identification object in the passage, the following is a summary of the system model and the frequency characteristics of the FSM system.
The mathematical model is determined by the electrical structure and mechanical structure of its [4,5], the physical equivalent mode of the FSM is shown in figure 3.

![Physical model equivalent in the FSM](image)

**Fig. 3 Physical model equivalent in the FSM**

The voice coil motor’s voltage and electricity are respectively $V$ and $i$. The electrical resistance and inductance are respectively $R$ and $L$. The back EMF voltage is $V_e$. Back EMF coefficient is $K_b$. Torque is $C_m$. Viscous friction coefficient is $f_m$. The spring stiffness is $K$. Load inertia is $J$. The relative balance of angular position turn over $\theta$. According to the equivalent physical structure of the FSM, there are the potential balance equations, back EMF and torque balance equation formula.

$$
\begin{align*}
Ri + Li' + V_e &= V \\
V_e &= K_b\theta' \\
J\theta'' + f_m\theta' + k\theta &= iC_m
\end{align*}
$$

(4)

The transfer function (5) can be deduced by simplifying the potential balance equation, the counter electromotive force formula and the torque balance equation.

$$
G_{FSM}(s) = \frac{C_m}{(Js^2 + f_m s + K)(Ls + R) + K_bC_m s}
$$

(5)

Thus, the fast steering mirror is a three order system, the fast steering mirror system is decomposed into series in the form of a two order oscillation and an inertia link.

$$
G_{FSM}(s) = \frac{k_1}{(k_2s^2 + k_6s + 1)(k_4s + 1)}
$$

(6)

In practical, due to a flexible supporting structure in the fast steering mirror system, the coupling phenomena appear is in high frequency. The true system’s open-loop characteristics at high frequencies is added to one or more of the formula (7) with mechanical resonance type dual two order link.

$$
G_{OSC}(s) = \frac{(k_2s^2 + k_5s + 1)}{(k_2s^2 + k_4s + 1)(k_4s + 1)}
$$

(7)

According to the measurement of the fast steering mirror openloop frequency characteristics [6] as shown in Figure 4, finally determine to identify the formula (8) for the transfer function model:

$$
G(s) = G_{FSM}(s) * G_{OSC}(s) = \frac{k_1(k_2s^2 + k_6s + 1)}{(k_2s^2 + k_4s + 1)(k_4s + 1)(k_5s + 1)}
$$

(8)
4 Identification Analysis

Considering of the mechanical resonance amplitude of open-loop frequency characteristics at high frequency domain is low, and is difficult to be fitted. So it is necessary to segment the whole transfer function. The bandwidth of experimental platform is 100Hz in this paper. Therefore, the fitting accuracy of the low frequency band below 100Hz is the key to ensure the validity of the designed controller.

The specific steps are as follows: first identifying the main part of the transfer function, then from the openloop frequency data subtract main transfer function in order to get high frequency of amplitude variation of mechanical resonance amplified. So the mechanical resonant link is easy to be identified.

According to the open-loop transfer function model, the number of the parameters of the main transfer function to be identified is four. In order to highlight the superiority of chicken group algorithm, algorithm and particle swarm optimization algorithm (PSO) are compared and analysed [7]. The number of population and the number of total particles were both 200, and the number of iterations was about 40. The results of the identification of the main transfer function is shown in Figure 5. Under the same conditions, the fitting results of the CSO algorithm are better than those of the PSO algorithm. The iterative convergence curve further shows that the chicken swarm algorithm is better than the particle swarm optimization algorithm on Figure 6.

Because the accuracy of the PSO algorithm is not high, the identification of high frequency mechanical resonance can not be carried out properly. Therefore, the identification of the mechanical resonance only uses the CSO algorithm.

Fig. 4 Openloop frequency characteristic of the FSM
Fig. 5 Fitting curve of the main transfer function

Fig. 6 Iteration curve of the CSO and the PSO

Fig. 7 Fitting curve of high frequency oscillation
Figure 8 shows the overall effect of using the CSO to fit the openloop transfer function, and Figure 9 shows that the identification error. In the range of 1 to 100Hz, we can find that the maximum amplitude error is 0.3648dB, and the maximum phase error is 4.618°. In the range of 100 to 1000Hz, the maximum amplitude error is 5.861dB, and the maximum phase error is 27.94°.

5 Conclusion
The swarm optimization and multi-cooperative optimizations of the CSO algorithm make it have the better search ability than the PSO algorithm. Especially in the high-dimensional parameter space, the search pattern of the CSO algorithm is more efficient than the traditional method based on the least square method and the gradient method. The using of the CSO algorithm in this paper realizes transfer function of the typical FSM identification to avoid the traditional identification method to estimate the parameters of the FSM. The proposed method successfully reduces the time of debugging and shorten the time of the whole control system design.
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