A Novel Modified Fly Optimization Algorithm for Designing the Self-Tuning Proportional Integral Derivative Controller

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Abstract

A novel Modified Fly Optimization Algorithm (MFOA) is proposed for determining the optimal Proportional Integral Derivative controller parameter. The Modified Fly Optimization Algorithm principle is elaborated and utilized to find effectively the optimal PID controller parameter. Some simulation results show that in contrast to the FOA-PID controller, the MFOA-PID controller is more optimal, effective and quick; Further, with respect to the Particle Swarm Optimization (PSO) PID controller, MFOA PID controller shows the close optimized performance in self-tuning PID controller, however, its searching speed is quite faster than PSO-PID.

Keywords: Optimal Control, Fly Optimization Algorithm, PID Controller, Particle Swarm Optimization

1. Introduction

With the rapid increase of the computing power of processors, robotics technology has attracted widely interest in research areas [1-5]. In order to ensure the excellent performance of robotic device, its motion and force relation has to be controlled accurately. This can be achieved through designing and implementing the motion control systems that can govern the motion and force relation in robotic device. There are various control approaches with their own structures, which can be employed for this purpose [6, 7]. Among those methods, the most common method is to use the classical Proportional Integral Derivative (PID) control method, which is applied in the industrial applications and robotics areas due to its simple construction, easy implementation, and robust performance[8][9]. However, tuning properly three parameters of the PID controller is quite difficult [10]. Several traditional methods, such as Ziegler-Nichols (Z-N) formula, Cohen-Coon approach and integral of absolute error rule (IAE) and so on [11-19], have been proposed to ascertain the desired parameters of PID. Recently, some new methods were introduced to improve the tuning techniques of the PID controller such as Genetic algorithm (GA), Particle swarm optimization (PSO), and fuzzy logic [20-26].

Wentsao Pan [27] proposes a new artificial intelligence optimization method called Fly Optimization Algorithm (FOA) with finding global optimization, based on the food finding behavior of the fruit fly [27]. Compared with other optimization algorithm such as GA and PSO, FOA has some advantages that its feature being easy to understand, it being implemented into program code, and meanwhile, its program code being not too long, are helpful to handle all kinds of optimization problems, etc [27, 28].

In order to acquire better performance than FOA, this paper proposes a Modified Fly Optimization Algorithm (MFOA) with high-quality solution within shorter calculation time and stable convergence characteristic. Based on the MFOA, a PID controller is designed and implemented by utilizing the MFOA to acquire automatically the proportional $K_p$, the integral $K_i$, and derivative optimal gains $K_d$.

The remainders of this paper are organized as follows. Section 2 describes the theory of FOA in detail. Section 3 proposes a better MFOA than FOA. Section 4 describes simply the PID
method. Section 5 demonstrates how to employ MFOA to acquire the optimal PID controller parameters. Section 6 is experiments and simulations, and shows the performance of the proposed MFOA approach and MFOA-PID controller. Section 7 concludes this paper.

2. Fruit fly optimization algorithm

As a result of being preferable to other species in olfactory sense and visual sense, the fruit fly can make full of utilizing its perception to find the food [27, 28]. Based on features and procedures of the fruit fly foraging, Wen-Tsao Pan has been presented a new Fly Fruit optimization algorithm (FOA) for discovering global optimization [27, 28].

FOA divided into seven steps, is depicted as follows [27, 28]:

1. As shown in Fig. 1, fruit fly swarm positions are initialized randomly as follow: \( \text{Init}_X \_ \text{axis} \) and \( \text{Init}_Y \_ \text{axis} \).

2. When the search orientations \( RV_x \) and \( RV_y \) of the fly fruit foraging with olfactory sense are given randomly, random distances of the foraging \( X_i \) and \( Y_i \) can be acquired in equation (1)

\[
\begin{align*}
X_i &= \text{Init}_X \_ \text{axis} + RV_x, \\
Y_i &= \text{Init}_Y \_ \text{axis} + RV_y.
\end{align*}
\] (1)

3. Since the food position is unknown, the random distances of the foraging \( X_i \) and \( Y_i \) to the origin is computed firstly (\( \text{Dist}_i \)), the smell concentration judgment value (\( S_i \)) calculated is equal to the inverse of distance in equation (2)

\[
\begin{align*}
\text{Dist}_i &= \sqrt{X_i^2 + Y_i^2}, \\
S_i &= \frac{1}{\text{Dist}_i}.
\end{align*}
\] (2)

4. Smell concentration judgment value (\( S_i \)) is substituted into smell concentration judgment function (Fitness function) in order to acquire the smell concentration (\( Smell_i \)) of the individual position of the fruit fly.

\textbf{Figure 1. Illustration of the group iterative food searching of fruit fly [27][29]}
\[ Smell_i = Function(S_i). \] (3)

5. The fruit fly with the best smell concentration (finding the optimum value) among the fruit fly swarm is located and obtained in equation (4)

\[ [\text{bestsmell, bestIndex}] = \text{Opt}(\text{Smell}) \] (4)

where \( \text{bestsmell} \) is the best or optimum value and \( \text{bestIndex} \) is location of \( \text{bestsmell} \) in fruit fly swarm.

6. The best smell concentration value and \( x \), \( y \) coordinate are kept; the fruit fly swarm will observe the position by vision and fly towards that.

\[
\begin{align*}
\text{Smell}_{\text{best}} &= \text{bestSmell} \\
X_{\text{axis}} &= X(\text{bestIndex}) \\
Y_{\text{axis}} &= Y(\text{bestIndex})
\end{align*}
\] (5)

7. Iterative optimization procedures are executed repeatedly from steps 2 to 5; the current iterative smell concentration value is compared with the previous; if the current is better, step 6 is executed.

3. Modified fruit fly optimization algorithm

In fact, on the basis of analyses and computations of the feature values \( S_i \) and \( \text{Dist}_i \) in equation (2), it is obvious that numerical values of \( \text{Dist}_i \) are distributed randomly in large-scale scopes. However, the large scope of \( \text{Dist}_i \) numerical values dealt with by \( S_i = 1/\text{Dist}_i \) in equation (2), causes that the scope of \( S_i \) becomes very small. When \( S_i \) is substituted into smell concentration judgment function (Fitness function) in equation (3), this directly causes the possibility of the premature convergence of FOA and makes FOA get into easily local optima.

It may be considered that a mathematical transformation is applied to broaden the distribution of numerical values \( S_i \) to avoid falling into local optima. Thus, in order to conquer the premature convergence effectively and improve the rate of convergence for FOA, a Modified Fly Optimization Algorithm (MFOA) is proposed through introducing \( \beta \) called as escape local optima factor in equation (7)

\[
\begin{align*}
\text{Dist}_i &= \sqrt{X_i^2 + Y_i^2} \\
S_{Mi} &= 1/\text{Dist}_i + \beta
\end{align*}
\] (7)

where \( S_{Mi} \) is expressed as the smell concentration judgment value in MFOA. To sum up the above arguments, two sorts of \( \beta \) are given in equation (8)

\[
\beta = \begin{cases} 
  g \times \text{Dist}_i \\
  K \times \text{IntiX_axis} \text{ or } K \times \text{IntiY_axis}
\end{cases}
\] (8)

where the first sort \( \beta \) is equal to \( g \times \text{Dist}_i \) with random variable \( g \) obeying uniform distribution, other is equal to the swarm position initialized randomly such as \( K \times \text{IntiX_axis} \) or \( K \times \text{IntiY_axis} \) with \( K \) being constant.

Thus, \( \text{Dist}_i \) and \( S_{Mi} \) of MFOA algorithm in equation (7) is different from those of FOA in equation (2). Further, a mathematical transformation shown in equation (7) by adding the escape
local optima factor \( \beta \), is employed to enlarge the distribution of numerical values \( S_i \) to avoid MFOA falling into local optima.

4. PID controller

The proportional controller is able to produce a change to the output which is proportional to the current error values. The integral controller is capable of reducing static state errors through adding a pole at the origin. The derivative controller can improve transient response through adding a finite zero to the open-loop plant transfer function. A transfer function of the norm PID controller is generally expressed in equation (9)

\[
G(s) = K_p + K_i \frac{1}{s} + K_d s
\]  

(9)

where \( K_p \) is the proportional gain, \( K_i \) is the integral gain and \( K_d \) is the derivative gain.

5. Design of MFOA-PID controller

A PID controller is designed and implemented by utilizing the MFOA to acquire automatically the proportional \( K_p \), the integral \( K_i \) and derivative optimal gains \( K_d \). The Model of MFOA-PID controller, is as desired as shown in Fig. 8 with Transfer Function being expressed as in equation (10)

\[
TranFun = \frac{s + 1.98}{s^4 + 7.96s^3 + 3.94s^2 - 0.97s + 0.39}
\]  

(10)

The Integral of Time multiply by Absolute Error (ITAE) index employed to design and evaluate the PID controller design method, is a popular performance criterion used for control system design [30]. ITAE index is expressed as in equation (11) as follow

\[
\text{ITAE} = \int_0^\infty |e(t)| dt
\]  

(11)

where \( e(t) \) is equal to the output minus input in Fig. 2.

A novel MFOA-PID controller is put forward for finding the optimal or close optimal controller parameters, \( K_p \), \( K_i \) and \( K_d \). Therefore, \( IntiX\_axis \) and \( IntiY\_axis \) of fruit fly swarm position are initialized respectively and randomly as two matrix, each of which is one row and three columns with position scope being all [0 300].

The search orientations \( RV_x \) and \( RV_y \) of the fly fruit foraging with olfactory sense are given randomly as two matrix, each of which is one row and three columns with position scope being all [-10 10]. Random distances of the foraging \( X_i \) and \( Y_i \) can be acquired in equation (1).
Since the food position is unknown, the random distances of the foraging $X_i$ and $Y_i$ to the origin is computed firstly ($Dist_i$). The smell concentration judgment value ($S_{mi}$) calculated is a 1x3 (one row and three columns) matrix and equal to the inverse proportion of distance in equation (7) with the second $\beta_i$ ranging randomly from [0 300]. The first column of $S_{mi}$ is represented as $K_p$, the second is $K_i$ and the third is $K_d$.

Smell concentration judgment value ($S_{mi}$) is substituted into smell concentration judgment function (Fitness function) in order to acquire the smell concentration ($Smell_i$) of the individual position of the fruit fly. Here, the ITAE index is employed as $Smell_i$.

In terms of the $Smell_i$ or ITAE, the optimum $Smell_i$ or the minimum ITAE can be found among the fruit fly swarm by equation (4). Corresponding to the minimum ITAE, the optimum gains and location of $K_p$, $K_i$ and $K_d$ can be acquired. The best smell concentration value ITAE, and x and y coordinate are kept.

Iterative optimization procedures are executed repeatedly as stated above; the current iterative smell concentration value ITAE is compared with the previous ITAE; if the current is better, iterative progress will stop.

6. Experiments and simulations

![Figure 3. Performance of MFOA-PID controller with the top subfigure being iteration process and the below being the step response transfer function in equation (10)](image-url)
Experiments and simulations are programmed by MATLAB 7.0 on WINXP operator and the hardware environment provided is a Intel(R) Core(TM)2 Duo CPU E7400 @ 2.80G with 3.0GB RAM.

To affirm the validity of the MFOA-PID controller in Fig. 2, a complex high-order system is as the test object with its transfer function in equation (10). As shown in Fig. 3, the results show that the MFOA method possesses high speed of convergence (32 iteration times) and acquire good evaluation value (ITAE being 1.1291) with members of fruit fly swarm and iteration number being all 100 times.

![Optimization process](image)

**Figure 4.** Performance of FOA-PID controller with the top subfigure being iteration process and the below being the step response transfer function in equation (10)

As shown in Fig. 4, the FOA-PID controller is also employed to adjust the transfer function of equation (10) to confirm that which is better effective between FOA-PID and MFOA-PID. By comparison, It is easily seen that the ITAE of the former is 16.907 and the latter is 1.1291. This indicates that the MFOA-PID controller is capable of finding more optimal, effective and quick PID controller parameters than the FOA-PID.

In order to verify the advantages of the represented MFOA-PID controller, the PSO-PID controller is also implemented based on literature [24]. PSO parameters are given as follow: Number of particles in a group is 100; Number of members in a particle are 3 including $K_p$, $K_i$ and $K_d$; Generations of iterations are also 100; Inertia weight factor is 2; Acceleration constant $C_1$ and $C_2$ are all equal to 2; ITAE index is employed as Fitness function.
As shown in Fig. 5, the results show that the PSO-PID method also possesses high speed of convergence (15 iteration times) and acquire good evaluation value (ITAE being 1.2744) with number of particles and iteration number being all 100 times.

More examples are employed to estimate respectively the performance of MFOA-PID and PSO-PID.
controllers in TABLE III. It can be found that both MFOA and PSO, two methods could give good PID controller parameters in every example with offering good stable output of step response, However, the searching speed of MFOA is far faster than PSO PID in TABLE 1.

7. Conclusion

In the paper, a novel Modified Fly Optimization Algorithm (MFOA) is developed to improve the FOA performance greatly.

In fact, the large space of $S_i$ numerical values transformed into small by $S_i = 1/Dist$, directly causes the possibility of the premature convergence of FOA and makes FOA get into easily local optima.

Through introducing escape local factor $\beta$, MFOA performance has been dramatically improved, for instance, MFOA possesses faster convergence performance than FOA, can jump easily local optima effectively, and find quickly the global minimum value with the convergence performance of MFOA being more steady and reliable.

In addition, the novel Modified Fly Optimization Algorithm is employed to implement the Self-Tuning PID Controller. The performance comparison between MFOA-PID controller and FOA-PID controller indicates that the MFOA-PID controller is capable of finding more optimal, effective PID controller parameters with shorter time than the FOA-PID.

The performance comparison between MFOA-PID controller and PSO-PID controller indicates that both MFOA-PID and PSO-PID can all produce good PID controller parameters with offering good stable output of step response, while searching speed of MFOA is obviously superior to PSO-PID. Besides, its feature being easy to understand, it being implemented into program code, and meanwhile, its program code being not too long, are helpful to handle all kinds of optimization problems.

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9. References


