A new Hybrid Infection model optimization Algorithm

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Abstract: In this paper, a new nature-inspired optimization algorithm, based on the prevalent mechanism of infectious diseases, called Hybrid Infection model optimization Algorithm（HIA）, was designed. The HIA algorithm mimic the transmission mechanism of infectious diseases, needs neither the gradient information nor the continuity of the search space. The comparison testing results of were showed that the new HIA optimization algorithm could works more efficient than some optimization algorithms in some cases.

Introduction

Optimization is one important research area of mathematical application. The most mainly optimize processing of optimization is using some methods to search the target solution space， under one constraint condition or more constraint conditions，for one special purpose or more special goals，to get the best or the worst solution or some specific max/min objects.

There are some typical optimization questions：Traveling Salesman Problem（TSP）、Scheduling Problem（SP）、Knapsack Problem（KP）、Bin Packing Problem（BP）、Max Clique Problem（MCP）etc.，all of these optimization questions have very important theory research values and application research values. All of optimization questions with exactly objects could be defined according to non-linear constraint conditions[1]：

$$\max imize \underset{x\in\Re^n}{/} \min imize: \quad f_i(x), \quad x=(x_1,x_2,...,x_n)^T \in \Re^n \tag{1}$$

$$\text{Subject to:} \quad \phi_j(x)=0, \quad (j=1,2,..,M), \tag{2}$$

$$\psi_k(x)\geq 0, \quad (k=1,2,...,N), \tag{3}$$

The $f(x)$、$\phi_i(x)$ and $\psi_j(x)$ in (1.1)(1.2)(1.3)are scalar functions of row vector. The every x_j in $x=(x_1,x_2,...,x_n)^T$ could be called the design variables，or the main variables，or the dominant variables，in this paper the x_j were unify called as the main variable/ variables s .

The optimization algorithm is one kind of search algorithm that using specific tactics to found the optimal solution or the best solution、the second solution、the second best solution or the alternative solution，in one or more specially solution space，under some certainly constraint conditions or without any constraint conditions[2].

The optimization algorithm，could be classed into many different types：the global search algorithm and the local search algorithm[3][4][5]; the constraint search algorithm and the unconstraint search algorithm[6]; the multi-object search algorithm and single-object search algorithm[7]; the deterministic search algorithm、the stochastic search algorithm and the hybrid/mixture search algorithm[8][9],etc..

Nature-inspired method

With the emergence of the genetic algorithm, the modern nature-inspired algorithm, as a kind of new meta-heuristic search method, has come into being in 1972. The nature-inspired algorithm is easy to solve the complex optimization problem that hard to deal with by the method of traditional optimization tech, such as engineering optimization、business planning、course arrangement、TSP、MCP、path planning , etc.

For its superior performance, the nature-inspired method is widely used in various kinds of optimization problems. At the same time, more and more new hybrid search algorithms based on nature-inspired emerge at the historic moment, such as: Simulated Annealing algorithm（SA）、Particle Swarm Optimization algorithm（PSO）、Ant Colony Optimization algorithm（ACO）、Harmony Search algorithm（HS）、 Cuckoo Search algorithm（CS）, etc. All of these new algorithms provide more new and better methods to solve more diverse difficultly hard-optimization problems.

These new nature-inspired meta-heuristic search algorithms, could quickly obtained the approximately solutions meet the requirement of accuracy，could meet the requirement of computing time，could solve the NP-hard problem and get the approximate solution， could solve a variety of difficultly hard-optimization problem and get the approximate solution on time[10][11].

So the new nature-inspired search algorithm with or without meta-heuristic tech，could be used to solve the NP-hard problem、hard-optimization problem for application of optimization[12][13]. The designs of hybrid nature-inspired search algorithm, are usually based on some kind of natural phenomenon of things by observation, and get the mathematical model of the natural phenomenon by mathematical abstraction.[14][15]

Then the math model of new algorithm should be converted into search and optimization algorithm step by step. In the end, the Hybrid Infection-based Nature-Inspired Algorithm was proposed and tested. The next，the design and implementation method of a new Hybrid search algorithm based on nature-inspired was introduced, the kind of Hybrid natural heuristic search algorithm based on infectious disease model, was named Hybrid Infection-based Nature-Inspired Algorithm（HIA）.

Infection search Algorithm

At present, in the area of Mathematical Biology, the model of infectious diseases has been researched for many years[16][17][18]. On the one hand, the model for a variety of infectious diseases, combined with the historical statistical data, more statistical analysis had been done，On the other hand, for the establishment of mathematical models and prediction of infectious diseases，more and more mathematical methods were introduced.

The SIR model belong to the simple discrete time model of infectious diseases，many other epidemic models could be deduced from SIR，such as without heal or temporary recovery concept is introduced，the SIR should become into SIS；when the total number of target sample could be changed and individual classification concept of different ages was introduced，the SIR should become into the Leslie model[19][20][21]. So the SIR model was chose as the mathematical model of the new hybrid natured-inspired optimization algorithm[22][23].

In HIA，the brownian motion was used as one-dimensional motion formula，then expanded it to two-dimensional motion formula.

The HIA algorithm init parameters setting needed to meet conditions as following：

$$S_{num} + I_{num} + R_{num} = N_{num} ; \qquad (4)$$

$0 \le \omega_s = S_{num} / N_{num} \le 1$； (5)

$0 \le \omega_i = I_{num} / N_{num} \le 1$； (6)

$0 \le \omega_r = R_{num} / N_{num} \le 1$； (7)

$\omega_s + \omega_i + \omega_r = 1$. (8)

Therefore, the system init parameters as following： $\omega_s = 1$、$\omega_i = 0$、$\omega_r = 0$ The end parameters of system as following ： $\omega_s = 0$、$\omega_i = 1$、$\omega_r = 0$ or $\omega_s = 0$、$\omega_i = 0$、$\omega_r = 1$ or $\omega_s = 0$、$\omega_i = \alpha$、$\omega_r = 1 - \alpha$.

The other needed determined parameters： the total period of infection T；the total sample of Group N；the total number of susceptible individuals S_{num}；the total number of infected individual I_{num}；The total number of individuals with immunity mechanic R_{num}；Contact coefficient β；the coefficient of was infected and after contact γ；Contact transmission coefficient $\Re_0$；ratio of Leave and join the total group of individual b. For initial value of each parameter，depending on the type of optimization problem be initialized. The total period of infection T，stand for total cycles times operated by HIA Algorithm，is experience parameters depending on the type of problem，by the calculate method $T = Counter = 1/\Delta_i$ and was set as 100 times.

The total sample of Group N was set as 1000，decided by the scope of the solution space. The S_{num}、I_{num} and R_{num}，at first，$S_{num} = N$、$\mathrm{I}_{num} = 0$、$\mathrm{R}_{rnum} = 0$，then the next generation S_{num}、I_{num} and R_{num} depended on β、γ、$\Re_0$ and b，the init value of HIA algorithm $\gamma = 1$、$b = 0$、$\beta = \Re_0$、$\Re_0 = 3$、α =0.3.

Hybrid Infection model optimization Algorithm，HIA

Begin

Objective function $f(x)$， $x = (x_1, x_2, ..., x_n)^T$

Initialize the S、I、R population，get $\omega_s = i_s$、$\omega_i = i_i$、$\omega_r = r_i$；

Initialize best solution-set N and the size of N;

Initialize parameters： β、γ、b、α；

Initialize iteration counter c，and set iteration increment Δi；

While ($b\beta > (\gamma + b)(b - b\gamma - b^2)$) or (c < max number of iterations))

Generate new solutions by infectious mechanism

if ($f(x)$ is better than every-element in N)

update the best solution-set N

else

Generate new solutions by Susceptible mechanism

end if

renew all $\omega_s = i_s - \Delta_i$、$\omega_i = i_i + \alpha\Delta_i$、$\omega_r = r_i + (1-\alpha)\Delta_i$；

renew all β、γ、b、α；

end while

end

Fig 1 pause code of the HIA

The filtration mechanism of evaluation function was designed by this method：if the terminating conditions are not satisfied， the evaluation function should pick out the most suitable solution candidate set and as the seeds of next round of iteration. The evaluation function for S_{t+1}、I_{t+1} and R_{t+1} as following：

$$num_{average} = \sum_{i=1}^{m} I_t \ , \qquad (9)$$

$$\rho = f(s_i) / num_{average} \ ; \qquad (10)$$

If $\rho > 1$, the solution of s_i belong to I_{t+1}; if $\rho < 1$, the solution of s_i belong to R_{t+1}; if $\rho = 1$, the solution of s_i should belong to I_{t+1} according to a random probability σ, else the solution of s_i belong to r_{t+1} according to a random probability $(1-\sigma)$.

The original dynamic constraints of HIA algorithm $0 < \beta b(1-1/\Re_0) < b\Re_0$ could be carried out by analyzing the following Jacobian matrix，if the limiting conditions of Jacobian matrix $b\beta > (\gamma + b)(b - b\gamma - b^2)$ could be meet，then，the HIA algorithm always could found appropriate solution. At the same time, another terminal condition decided by the variable of the total period of infection T. The most simple method of terminal condition could designed by this formula：

$$T = Counter = 1 / \Delta_i \qquad (11)$$

Another terminal condition is that the counter of HIA had reached predetermined times of iterations, or, the optimal solution of HIA algorithm without any improvement after the set times of iterations had been reached.

Test function and experiments

There are many benchmark test functions in literature，and they are designed to test the Performance of optimization algorithms. Any new optimization algorithm should also be validated and tested against these benchmark functions. All of test results should be compared and analyzed as following table 1、table 2.

Test function 1：De Jong's fuction

$f(x) = \sum_{i=1}^{n} x_i^2$; $-5.12 \le x_i \le 5.12$, $i = 1, 2, ..., n$; the mini value lied in $f(x_i) = 0$, $x_i = 0$, $i = 1, 2, ..., n$.

Test function 2：Axis parallel hyper-ellipsoid function

$f(x) = \sum_{i=1}^{n} (i \times x_i^2)$; $-5.12 \le x_i \le 5.12$, $i = 1, 2, ..., n$, $x_i = 0$, the mini value lied in $f(x_i) = 0$, $i = 1, 2, ..., n$.

Test function 3：Easom's function

$f(x) = -\cos(x)\cos(y)\exp(-(x-\pi)^2 - (y-\pi)^2)$; $-100 \le x_i \le 100$, $i = 1, 2, ..., n$; when $x_i = 0$, the mini value lied in -1， $i = \pi, \pi, ..., \pi$.

Test function 4：Rosenbrock's function

$f(x) = \sum_{i=1}^{n-1} [100(x_{i+1} - x_i^2)^2 + (1 - x_i)^2]$; $-2.048 \le x_i \le 2.048$, $i = 1, 2, ..., n$, when $x_i = 0$, the mini value $f(x_i) = 0$, $i = 1, 2, ..., n$.

Test function 5：Ratrigin function

$f(x) = 10n + \sum_{i=1}^{n-1} [x_i^2 - 10\cos(2\pi x_i)]$; $-5.12 \le x_i \le 5.12$, $i = 1, 2, ..., n$; $x_i = 0$, the mini value $f(x_i) = 0$, $i = 1, 2, ..., n$.

The test hardware environment of HIA algorithm is proposed as following：notepad IBM thinkpad x61，Intel（R） Core（TM）2 Duo CPU，T7500，main frequency 2.2GH，memory2G；

and，Matlab R2011b be used as Simulation software. The total statistical time of HIA algorithm that found the optimum solution or the approximate solution，was expressed as Time(seconds/s). The Accuracy Rate was used as the average time index that gets the same global optimal solution or found the best approximate solution deviation less than 3 percent after run 60times. The standard PSO algorithm and the Simulated Annealing Algorithm were used to compare with HIA algorithm. The results of compared were listed as following (Table 1 Table 2):

Function	**PSO**		**HIA**	
	Time(s)	**Accuracy Rate**	**Time(s)**	**Accuracy Rate**
Function 1	42.6762	100%	43.0288	100%
Function 2	42.6877	100%	42.8423	100%
Function 3	41.2156	100%	46.2066	100%
Function 4	56.6264	97%	52.0006	81%
Function 5	58.2192	85%	58.4392	80%

Table 1： The test results of HIA compared with PSO

Function	**SA**		**HIA**	
	Time(s)	**Accuracy Rate**	**Time(s)**	**Accuracy Rate**
Function 1	43.1817	100%	43.0288	100%
Function 2	42.9373	100%	42.8423	100%
Function 3	43.5123	100%	46.2066	100%
Function 4	54.5567	100%	52.0006	81%
Function 5	54.9924	94%	58.4392	80%

Table 2：The test results of HIA compared with SA

In table 1，the parameter Settings of PSO are as follows: the particle number n = 20, the number of iterations is 100 beta = 0.5, gamma = 0.7. In table 2，the parameter Settings of SA are as follows: the initialization temperature is 1, the iteration stop temperature is 1e - 10, the cooling factor for alpha = 0.9, the energy E is 1e-5, the maximum number of iterations is 500.

The experimental results show that HIA algorithm can quickly generate more random candidate source distribution, and can quickly move towards their own local best or worst value. The HIA algorithm has good convergence and can quick search to the global optimal solution with fewer times of iterations. For some optimization instances，the HIA algorithm has faster speed for search better approximate solution or search the best solution more precisely.

Conclusions

For imitating the spread mechanism of infectious diseases，the HIA algorithm needs the spread transmission way of disease and the incremental iteration movement of the every generation new sources of infection.

At the same time，the concept of effective radius of influence, the infection factors etc. were introduced into the HIA algorithm，and all these concepts indeed increase search speed that found the candidate solution set around the target neighborhood.

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