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Novel adaptive bacterial foraging algorithms for global optimisation with application to modelling of a TRS

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ABSTRACT

In this paper, adaptive bacterial foraging algorithms and their application to solve real world problems is presented. The constant step size in the original bacterial foraging algorithm causes oscillation in the convergence graph where bacteria are not able to reach the optimum location with large step size, hence reducing the accuracy of the final solution. On the contrary, if a small step size is used, an optimal solution may be achieved, but at a very slow pace, thus affecting the speed of convergence. As an alternative, adaptive schemes of chemotactic step size based on individual bacterium fitness value, index of iteration and index of chemotaxis are introduced to overcome such problems. The proposed strategy enables bacteria to move with a large step size at the early stage of the search operation or during the exploration phase. At a later stage of the search operation and exploitation stage where the bacteria move towards an optimum point, the bacteria step size is kept reducing until they reach their full life cycle. The performances of the proposed algorithms are tested with various dimensions, fitness landscapes and complexities of several standard benchmark functions and they are statistically evaluated and compared with the original algorithm. Moreover, based on the statistical result, non-parametric Friedman and Wilcoxon signed rank tests and parametric *t*-test are performed to check the significant difference in the performance of the algorithms. The algorithms are further employed to predict a neural network dynamic model of a laboratory-scale helicopter in the hovering mode. The results show that the proposed algorithms outperform the predecessor algorithm in terms of fitness accuracy and convergence speed.

1. Introduction

The twin rotor system (TRS) is a highly nonlinear dynamic system, which is often used as a platform to test controllers. It is a laboratory scale equipment that mimics the behaviour of a real helicopter. A schematic diagram of the twin rotor system is shown in Fig. 1. The main rotor moves the system up and down while the tail rotor rotates the system horizontally about the yaw-axis. The vertical and horizontal motions and multi-input multi-output nature of the system lead to complex characteristics which are difficult to model.

Several conventional techniques have been used to acquire dynamic model of a twin rotor system. The techniques are based on system identification or parametric method, time-series regression, auto regressive with exogenous inputs (ARX) model, auto regressive moving average (ARMA) model and auto regressive moving average with exogenous inputs (ARMAX) model. These estimated models are mostly linear and have limited capability to capture non-linearity behaviours of the twin rotor system thus result in inaccurate model. Non-parametric approaches such as expert systems, artificial neural networks (ANNs) and fuzzy logic have been developed more recently to estimate dynamic model of various types of flexible systems with more promising and accurate results. The nonparametric approach is more robust and more accurate than the parametric approach. The prediction of a dynamic model for a flexible system using ANN is gaining attention from researchers due to its learning ability. However, the performance of ANN to predict the behaviour of a flexible system is still facing a drawback because of its complex and nonlinear nature, which is difficult to determine. Moreover, the optimum model of the ANN using conventional optimization algorithm such as gradient-based algorithm, steepest descent algorithm and least square algorithm is likely difficult to achieve since they tend to get stuck into local optima solution. Recently, the application of bio-inspired optimization algorithm like Bacteria foraging algorithm (BFA) to

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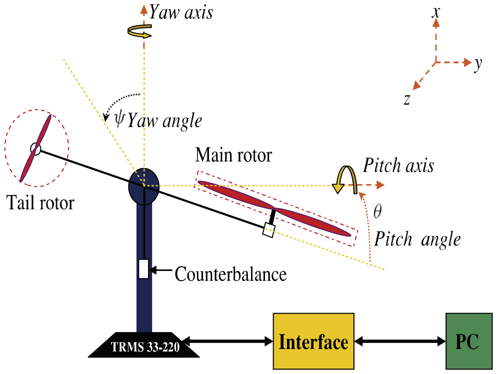

Fig. 1. Schematic diagram of a twin rotor system (Reprinted from: Toha et al., 2012).

Table 1
Parameter of the BFA and adaptive BFA.

Parameter	Description
p	Dimension of search space
$J(I,P)$	Fitness cost of ith bacterium at current iteration
S	Total number of bacteria
C	Constant step size
N_c	Total number of chemotaxis
N_s	Maximum number of swim
sw	Index of swim
N_{re}	Maximum number of reproduction
N_{ed}	Maximum number of elimination and dispersal
i	Index of a bacterium
j	Index of chemotaxis
k	Index of reproduction
L	Index of elimination and dispersal

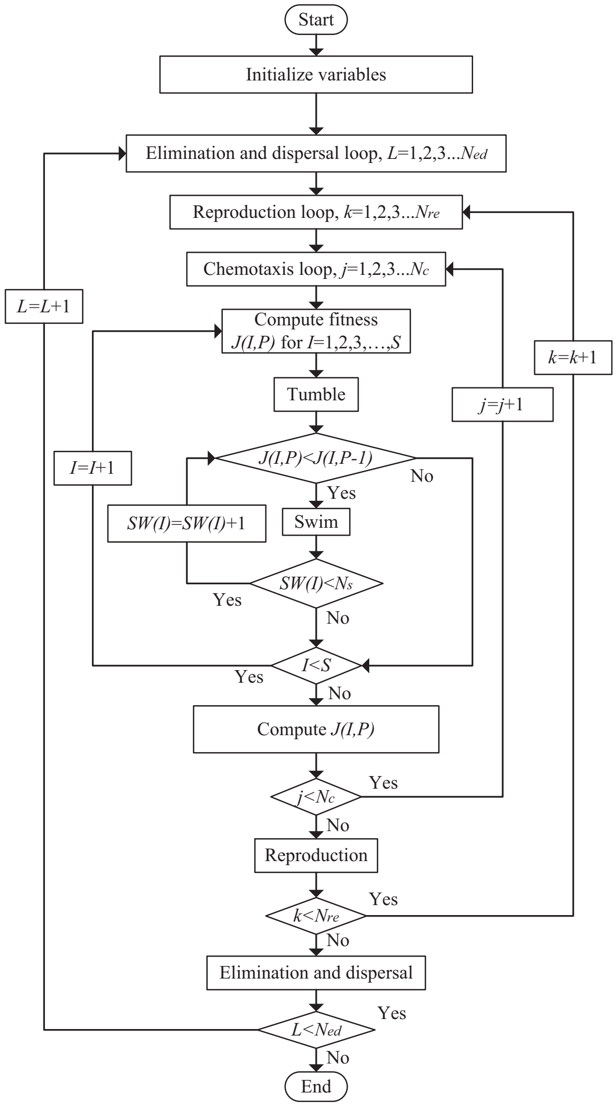

Fig. 2. Flowchart of the original and adaptive BFA.

predict nonlinear behaviour of a dynamic model is gaining more interest and has resulted in more accurate performance (Devi & Geethanjali, 2014; Ulagammai, Venkatesh, Kannan, & Padhy, 2007).

Bio-inspired optimization algorithms have gained attention from researchers around the world due to their capability in dealing with numerous real world applications and the reliability of producing optimum solutions. Some of the well known bio-inspired algorithms include genetic algorithm (Goldberg, 1989), particle swarm (Kennedy & Eberhart, 1995), ant colony (Dorigo & Di caro, 1999), artificial bee colony (Karaboga & Basturk, 2007) and BFA (Passino, 2002). BFA is one type of bio-inspired optimization algorithm which mimics the foraging strategy of *Escherichia coli* (*E. coli*) bacteria. The strategy is based on the bacteria behaviour to find rich nutrient or optimum food source during their full lifetime cycle which consists of chemotaxis, reproduction, elimination and dispersal phases. The chemotaxis phase through random tumble and swim mechanism is the most prominent phase of the foraging strategy where it mostly affects the success and performance of the bacteria to look for highest nutrient source. In this phase, the movement of bacteria from one location to another location is faster if a large step size is defined. However, the drawback of this choice is that the bacteria may be unable to locate the rich nutrient source if it is located at a remote area or at a minimum point of a curve. From an optimization point of view, this option can expedite the algorithm's convergence but it produces relatively low accurate solution and leads to oscillation around the optimum point. On the contrary, the optimum nutrient source location might be easily found if the bacteria are moving with smaller step size. Nevertheless, the limitation of this option is that the bacteria require more steps and more time to reach the optimum food source. In other words, the convergence speed of the algorithm to an optimum point is slower but high accurate solution can be attained. In order to overcome such problems, variation of bacteria step size in both tumble and swim actions throughout the search operation might be introduced. This can be realised through adaptation of a certain relationship such as using mathematical formulation, fuzzy logic approach, etc. The reproduction phase is an important process to preserve the fittest and healthiest bacteria in the population. After completing the chemotaxis phase, all the bacteria are classified based on their health and fitness level. The first half of the classified bacteria, which is considered as healthier than the other half of the bacteria population is reproduced. In order to maintain only the fittest bacteria in the population, the other half of the bacteria with lower health and fitness is eliminated. The reproduction process of the fittest bacteria can speed up the foraging strategy of the bacteria. To make the foraging strategy faster, a dispersal phase is introduced where all bacteria in the population are distributed randomly within the search area. With this strategy, the probability for the bacteria to be relocated at closer position to the optimum nutrient or food location is increased. This process takes place in the elimination and dispersal phase. Those three major processes of foraging strategy are performed in a sequential order and they are continuously repeated until full life cycle of bacteria is reached.

There are several adaptation mechanisms previously adopted by researchers to improve BFA performance. Mishra (2005)