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Research paper

A Comprehensive Review of the Pigeon-Inspired Optimization Algorithm

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Abstract

Optimization is the essence of most of the decisions one has to make, whether it is some complex engineering design or just be a simple holiday planning. Fundamentally, most of the optimization problems are solved using traditional methods of numerical computing. However, while addressing complex engineering problems, these methods exhibit some short falls as they are sensitive to initial values and fail to attain consistency in global solutions. In contrast, researchers proposed contemporary algorithms mostly on the basis of 'learning' strategies. Most of these algorithms are nature-inspired algorithms. Swarm Intelligence is one very predominant nature inspired optimization technique based on social organisms such as bacteria, bees, ants, fireflies, pigeons etc., for finding solutions to optimization problems. This paper mainly focuses on reviewing a newly developed bio-inspired optimization approach, namely, Pigeon Inspired Optimization (PIO) algorithm. Pigeons are simple and intelligent birds, which can travel long distances in search of food and return home without getting lost. This act inspired researchers and led to the interpretation that pigeons navigate using Earth's magnetic field, differences in altitude of sun and by remembering few landmarks. The success of any algorithm is assured when the algorithm is able to explore and exploit globally in the problem domain. Probing PIO on various applications helps us to understand the algorithm better.

Keywords: *Pigeon Inspired Optimization, Optimization, Nature Inspired Algorithm, Swarm Intelligence.*

1. Introduction

The procedure of finding best compromise between the parameters is the simplest explanation for an optimization process. Earlier traditional methods were used extensively for solving optimization problems. As the technological advancement started, Traditional Algorithms (TA) failed to fulfill the needs of the complex problems which are mentioned below:

- Problems which are nonlinear, discontinuous, and multimodal are difficult to solve.
- TA mainly confines to local search.
- In most cases TA are problem-specific because they usually use derivative information for solving.
- In TA, the final solutions will be similar when identical initial points are considered. Thereby, TA lacks diversity of the obtained solutions.

In order to overcome these limitations of the TA, contemporary algorithms viz. heuristic and metaheuristic were proposed. The approach of heuristic algorithms is to use trail-and-error method in generating new solution, while metaheuristic algorithms use recollection of a history of solutions and improvises the solution i.e., learning approach. Therefore, metaheuristic algorithms are also called as high-level heuristic algorithms. In the recent past, most of these metaheuristic algorithms are nature-inspired algorithms which work on the Swarm Intelligence (SI). Nature has always been a great inspiration and motivation for some of the researchers which led to the development of algorithms based on the swarm behavior of many social organisms like fireflies, bees, cockroaches, mosquitoes, bacteria, pigeons etc., in finding solutions to optimization problems [1].

Typically, SI is a branch of artificial intelligence expressing the collective behavior of organisms which are self-organized. To mimic such a behavior, SI algorithm generates a population which consists of randomly deployed agents. Thus, in this methodology, these agents interact locally with one another and also with the surrounding environment [2]. The intention of deploying these agents is to create certain degree of random behavior. Thereby, there is no centrally controlled structure dictating the individual behavior. Moreover, these deployed agents have an intelligent behavior while interacting with other similar agents [3]. It is observed that in the last 25 years a large number of nature inspired algorithms have been developed. Most of these algorithms possessed some unique abilities such as randomness during each execution, independence of initial values and also uniqueness in the path it travels to find the solution.

Pigeon Inspired Optimization (PIO) is a newly developed SI optimization method. Pigeons are simple and intelligent birds which were once used to communicate messages. The homing pigeon has an inborn homing ability to find its way home over extremely long distances. Inspired by these birds, researches on PIO have been proposed by Haibin Duan [4]. It is believed that pigeons use a combination of the altitude of sun, the Earth's magnetic field and landmarks to find their way home.

2. Pigeon Inspired Optimization Algorithm

Pigeons are estimated to fly long distances in search of food [5]. They are equally skillful and swift at flying through a forest as through the open space. Another interesting ability is that, the pigeons can find their route back to their home with their ability to sense Earth's magnetic field, the sun's altitude and visual clues like landmarks. Leading pigeons in the group communicate with rest of the flock and navigates by maintaining a side by side flocking distance.

Leadership of a pigeon is determined on the basis of number of times a particular pigeon communicates with the other pigeons in a given random population. Thereby, a fitness function f(x) is assigned to that leading pigeon. Upon investigating the behavior of pigeons, it was revealed that some species have a kind of magnetic particles in their beaks which carry signals to the brain by a trigeminal nerve [4].

2.1. Mathematical Model of PIO

In pigeons, the homing characteristics can be mathematically depicted by two main operators by some rules as follows:

2.1.1. Map and Compass Operator:

As per the map and compass operator model, the pigeons are believed to sense the Earth's magnetic field by magnetoreception and form some sort of map in their brains. Further, the pigeons also observe the sun's altitude and use this information as a kind of compass to adjust their direction. However, as they get closer to their destination (hometown), pigeons depend less on map and compass operator.

For simplicity, in the computer simulated pigeons, the position and velocity of pigeon 'i' can be denoted by X_i and V_i, which is updated for every iteration in a D-dimensional search space. The new position and velocity of pigeon 'i' at the t^{th} iteration is given [4] by

$$V_i(t) = V_i(t-1).e^{-RT} + rand.(X_g - X_i(t-1)) \tag{1}$$

$$X_i(t) = X_i(t-1) + V_i(t) \tag{2}$$

where R is given by map and compass factor, *rand* is a random number generated from a uniform distribution on [0,1]. The current global best position calculated by comparing all the positions is given by X_g.

Figure 1 depicts the map and compass operator model of PIO. By comparing the directions of all the pigeons, it can be observed that the right-centered pigeon's position is the best one among all the flock of pigeons. The remaining pigeons which have deviated from their expected destination adjust their flying directions by following the best pigeons' path, which is indicated by the thick arrows in figure 1. Whereas, the thin arrows represent their former flying direction, which has relation to $V_i(t-1).e^{-Rt}$ in equation 1. The next flying direction is a vector sum of these two arrows.

2.1.2. Landmark Operator:

As the pigeons fly closer to their destination, they try to recognize the surrounding landmarks and neighboring patterns. If right landmarks are recognized, the pigeons fly directly to their destination. Otherwise, they will try to follow the pigeons who are familiar with the land marks. During computer simulation, it is assumed that the pigeons are far from their destination and are not able to recognize the landmarks. Therefore, the pigeons are ranked according to their fitness values. Then half of the pigeons (N_p) is decreased according to the below formula

$$N_p(t) = \frac{N_p(t-1)}{2} \tag{3}$$

Thus, the central pigeon as an example shown in figure 2, has a position with desirable destination while rest of the pigeons which still struggle to find their destination will follow this central pigeon.

The current position of the central pigeon at the t^{th} iteration, is calculated by using X_i, whereas the position (X_c) is the desirable destination. The new position of other pigeons can be calculated by

$$X_c(t) = \frac{\sum X_i(t).fitness(X_i(t))}{N_p \sum fitness(X_i(t))} \tag{4}$$

$$X_i(t) = X_i(t-1) + rand.(X_c(t) - X_i(t-1) \tag{5}$$

where *fitness*($X_i(t)$) is the fitness value of each pigeon in the swarm. For the minimization optimization problem, we can choose $fitness(X_i(t)) = \frac{1}{f_{min}(X_i(t))+\delta}$ where δ is a small positive number. For maximum optimization problems, we can choose $fitness(X_i(t)) = f_{max}(X_i(t))$. For each individual pigeon, the optimal position of the N_c^{th} iteration can be denoted by X_p, where X_p=min ($X_{i1}, X_{i2}, \ldots, X_{iNc}$).

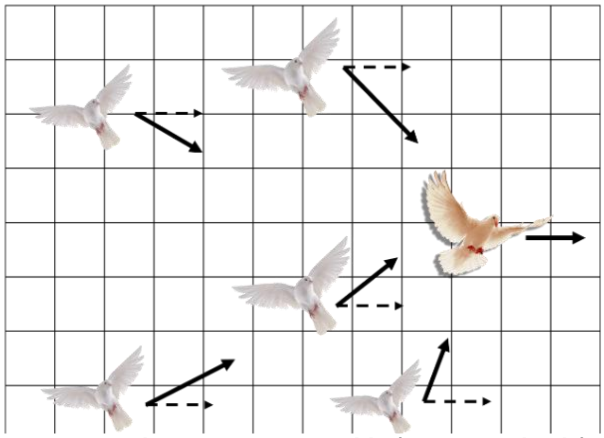

Figure 1: Map and Compass operator model of PIO. (Reproduced from [2])

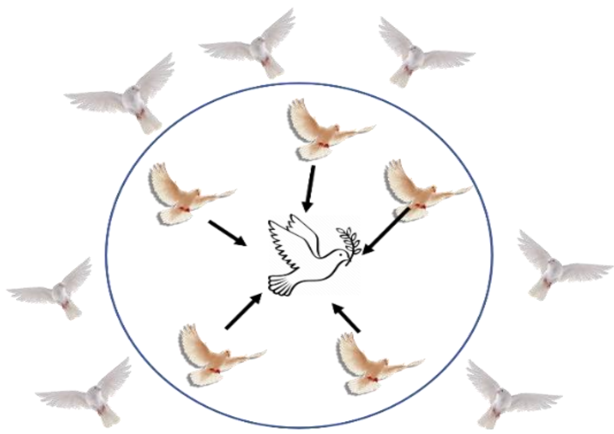

Figure 2: Landmark operator model. (Reproduced from [3])

In the figure 2, the pigeon at the center of the circle is considered to be in the right direction and all the pigeons inside the circle have identified their destination. Half of all the other pigeons, which are out outside the circle, are far from their destination and are most likely to follow the pigeons that are close to their destination. There may also be a case where two pigeons may be at the same position. The pigeons that are close to their destination inside the circle will fly to their destination quickly.

2.2. Basic Procedure of PIO

The steps involved in the computer simulated sequence of execution of PIO can be expressed as follows:

Step 1: Initialize the topographic information.
Step 2: Initialize PIO parameters such as solution space dimension D, the population size N_p, map and compass factor R, the number of iterations N_{C1} max and N_{C2} max for two operators, and N_{C1} max > N_{C2} max.
Step 3: Prepare each pigeon with a random velocity and path. Evaluate the fitness of each pigeon and find the current best path.
Step 4: Update the velocity and path of each pigeon by applying equations 1 & 2 and evaluate the fitness functions of all the pigeons. Compare all the fitness values to set the new best path.
Step 5: Check if N_C > N_{C1} max, then stop the map and compass operator and go to the next operator. Else go to Step 4.
Step 6: Sort and rank all the pigeons as per their fitness values. Consider only half of the pigeons with poor fitness to follow the best fitness pigeons with respect to the equation 3. Then, the desirable destination center is calculated using the equation 4. Thereby, all the pigeons will adjust their positions and fly according to the equation 5. Also, the best solution along with their parameters are stored.
Step 7: If N_C > N_{C2} max, stop the landmark operator, and evaluate the results. Else, go to step 6.

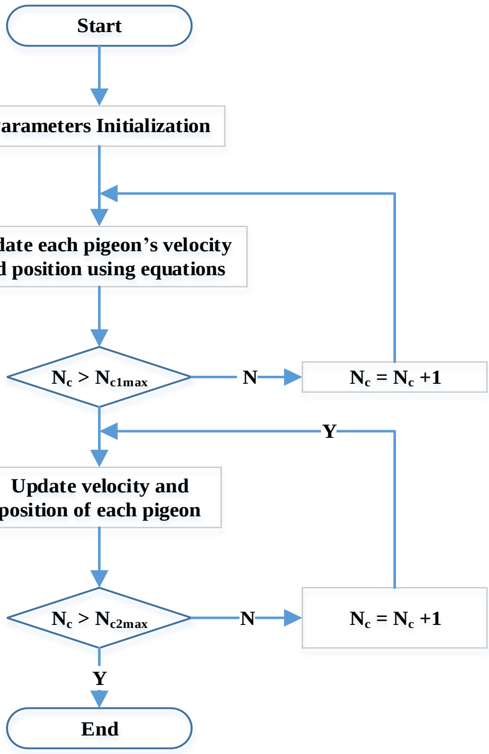

Figure 3: Flowchart of basic PIO (Reproduced from [3])

Algorithm 1: Basic PIO pseudo code
Parameters initialization
Set initial path Xi for each pigeon
Set Xp = Xi, Nc = 1
Calculate fitness values of different pigeons
Xg = min [f(Xp)]
for Nc=1 to Nc1max do
for i=1 to Np do while Xi is beyond the search range do
Calculate Xi
end
end
Evaluate Xi, and update Xp and Xg
for Nc = Nc1max+1 to Nc2max do
while Xp is beyond the search range do
Rank all the pigeons as per their fitness values
NP = NP/2
Keep half of the individuals with better fitness values
Xc=average value of the paths of the remaining pigeon
Calculate Xi
end
Evaluate Xi and update Xp and Xg
end
Xg is output as the global optima of the fitness function f

3. Applications of PIO in Engineering

The engineering applications of PIO are reviewed by grouping them into relevant applications such as Aerospace Technology, Power Systems & Energy Management, Image Processing, Controller Design and others.

3.1. Aerospace Technology

Unmanned Aerial Vehicles (UAVs) are becoming more popular in many fields ranging from civil to military. Although UAVs have demonstrated their advantages, they lack confidence because of two main problems namely, control system and path planning system. Many researchers have found that the newly developed PIO algorithm showed feasible and effective solution to aerospace technology. Some of the important literatures in the aerospace technology are Xiaomin Zhang et al.[3], Jiang Zhao & Rui Zhou [7], Rui Dou and Haibin Duan [8], Qiang Xue & Haibin Duan [9], Gangireddy Sushnigdha & Ashok Joshi [10]. In these papers PIO has proven to outperform the popular SI algorithms such as Particle Swarm Optimization and Gravitational Search Algorithms.

3.2. Power Systems & Energy Management

Another important application of PIO is the optimization of power systems and energy consumption. Aeidapu Mahesh [11] has applied PIO for optimal sizing study of hybrid PV/wind energy system with battery storage. In order to minimize the total system cost while satisfying reliability constraint and maintaining the healthy charge on the battery, PIO showed better results. Similar work was reported by Pei Jai Zheng et al. [12], Saadia Batool et al. [13], Zunaira Amjad et al. [14], Hafsa Arshad et al. [15].

3.3. Image Processing

Computer vision is one of the most active research topics, for numerous applications in the fields of augmented reality, photogrammetry, and robotics. Researchers have adopted PIO algorithm for robust and accurate pose estimation in binocular camera systems [6], obtaining optimal threshold value for automatic detection of image and extract its features [16], optimization of image fusion, i.e., an integrated information from multiple sensor images and adapting the new image for visual observation and computer processing [17].

3.4. Controller Design

In many applications, designing an optimized, robust control system with fast, accurate and stabilized responses is one of the major challenges. Researchers have employed PIO algorithm for addressing this issue, [18], [19], [20]. The experimental results also validate the effectiveness and robustness of the PIO algorithm.

3.5. Other Applications

PIO has been employed in many diverse applications such as robotics, optimization, and biological processes etc. Haibin Duan

& Peixin Qiao [4] & [21] applied PIO for air robot path planning. Ziujuan Lei et al. [22], and Wei Zheng et al. [23] both have used PIO algorithm for detecting protein structure accurately in relatively short iterations. It was also used for simply finding the shortest path from a given source such as a travelling salesman problem etc. [5].

4. Conclusions

Despite the success of PIO algorithm, there are some key areas to be explored further. Few of them are summarized as follows:
i. Theory: According to Fitak RR et al. [24], it has been observed that there are numerous other animals which can also detect Earth's magnetic field and use it for navigation. Researchers have also started exploring on two proposed mechanisms. The first is a chemical magneto-reception that reacts biochemically under the influence of Earth's magnetic field. The second mechanism encompasses a crystal of mineral magnetite which plays a vital role to transduce magnetic stimuli to the nervous system. Therefore, more theoretical analysis is needed.
ii. Hybridization: Hypothetically, hybridization of two or more algorithms may lead to a better outcome. However, there is no standardized selection procedure which may result in better co-evolution of both the algorithms.
iii. Applications: Although, PIO is a very simple and easy-to-apply algorithm, there could be more diversified areas of application in addition to the applications reviewed in this paper. PIO has got limited recognition due to lack of understanding its basic working principle and opportunity in applying.
The PIO algorithm has a strong potential due its faster convergence and simple steps for solving problems in many applications. The authors of this paper would like to provide the overview of the PIO and inspire future researchers in the direction of more real-world applications.

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