Pastoralist Optimization Algorithm (POA): A Novel Nature-Inspired Metaheuristic Optimization Algorithm

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Abstract—*This paper proposes the development of a novel optimization algorithm called the Pastoralist Optimization Algorithm (POA) inspired by the pastoralists herding strategies. The strategies are scouting, camp selection, camping, herd splitting and merging. These strategies were modelled mathematically and used to develop the POA. The performance of the algorithm was evaluated by testing the algorithm on 10 unimodal and multimodal test benchmark functions. This is to measure the algorithm exploitative, explorative, convergence speed as well as the ability to escape being trapped in a local optimum solution. Also, a nonparametric statistical test (Wilcoxon rank sum tests) was carried out to ascertain the statistical significance level of the proposed algorithm results. The experimental results obtained show that the algorithm is very competitive and obtain better results in most cases when compared with some similar existing state-of-the-art nature-inspired metaheuristic optimization algorithms. Also, it is statistical proven tht the results are very significant.*

Keyword— Algorithms; Benchmark test functions; Nature inspired metaheuristic algorithms; Pastoralist Optimization Algorithm

1 INTRODUCTION

The rapid growth in technology has brought to the fore the need for faster and more accurate solutions to emerging complex real-world problems. As technology advances and our understanding of real-world Optimization problems (OP) (with their sometimes complex, multi-modal, non-linear and dynamic nature) also improves, it then becomes imperative to continue to seek for new solutions to these emerging problems in nature. Despite the successes recorded by most developed state-of-the-art meta-heuristic Optimization Algorithm (OA) inspired by different natural phenomenon to solve wide range of emerging real-world OP [1], no single OA can provide the most appropriate solution to all OP. Hence, developing a new OA that could provide better solution to some OP is still an open research problem in this field [2].

Examples of some successful NI-OA's and their inspirations include; Biogeography-based Optimization [3] inspired by the geographical distribution of biological organisms, Artificial Bee Colony [4] inspired by the foraging behavior of bees. Teaching Learning Based Optimization [5] inspired by classroom teaching and learning, Imperialist Competitive Algorithm [6] inspired by human socio-political evolution process. Others are; Grasshopper Optimization Algorithm [7] inspired by the swarming behaviors of Grasshoppers, Ant Lion Optimizer [8] inspired by the behavior of ant lion and Lion optimization algorithm [9] inspired by special behaviors of lions. This paper proposes the development of a novel NI-OA inspired by pastoralist herding strategies called Pastoralist Optimization Algorithm (POA).

This paper is structured as follows: In Section 1, optimization and review of related works were presented. In section 2, the proposed POA is presented followed by the experimental results and discussion in Section 3 and finally, conclusion and recommendation in Section 4.

2 PASTORALIST OPTIMIZATION ALGORITHM (POA)

In this section, the inspiration behind the proposed POA is discussed. This is followed by mathematical modelling of each pastoral herding strategy and the proposed POA.

2.1 Inspiration

Pastoralism is a socio-economic livestock production system characterized by extensive movement of animals in search of quality pastures and water [10]. Nomadic pastoralism among other forms of pastoralism (transhumance, semi-nomadic and sedentary) is a highly sustainable and flexible system that allows the pastoralists to manage livestock, environment and people efficiently using some highly flexible strategies. These strategies help the nomadic pastoralists to survive the unpredictable and potentially hazardous pastoral life [11]. The strategies adopted by the nomadic pastoralist include the following:

Scouting [12], Camp Selection and Camping [13], Splitting/Herd Dispersal, [14], Merging and Selection of New Camp, [15]. These strategies make nomadic pastoralism a potentially good candidate for the development of an optimization algorithm. In POA, a set of pastoralists were randomly generated to form the initial population of the search space. 25% of pastoralists are selected as scout pastoralists from the initial pastoralist population [12]. The scout pastoralists search for the best location for camping. The camps with a given radius are temporary locations where daily herding to other locations within the search area takes place. The size of the camp also depends on the size of herds and search space. During herding, pastoralist split themselves to minimize risk of getting stuck or better grazing for animals where resources are limited. This is followed by merging where the fitness of each pastoralist is evaluated and the decision for a new camp search is taken.

2.2 Proposed POA

The nomadic pastoralist strategies described under section 2.1 were modeled mathematically as follows:

2.2.1 Initialization

The first step in developing the POA is to generate the population of pastoralist (nP) randomly because POA is a population-based metaheuristic algorithm. In POA, a solution is called a pastoralist which is represented in the search space as:

$$P = [P_1, P_2, P_3, \dots, P_D] \quad (1)$$

Where, P is the pastoralist and D is the dimension or number of variables of the optimization problem. The second step is to select (25%) of the pastoralist as scout pastoralist (S) represented as;

$$S = [S_1, S_2, S_3, \dots, S_D] \quad (2)$$

2.2.2 Scouting

After selecting the number of scout pastoralist, their locations are initialized randomly within the search space using Equation (3) and followed by evaluation of fitness of each scout. The fitness of scout j is evaluated using Equation (4) followed by sorting and selection of best scout until scouting rate is maximum, else, the scouts move into a new location guided by the previous best location using Equation (5).

$$S_i = rand([L_b, U_b]^D) \quad (3)$$

$$F(S_i) = FF(S_i) \quad (4)$$

$$S'_i = (S_{best} - S_i) + \varepsilon_i * \eta_i * \zeta \quad (5)$$

Where $rand([L_b, U_b]^D$ is a D-dimensional random vector between the lower bound and upper bound of the search space and FF is the fitness function, s′ is the new location of scout j around the best-found location S_{best}, ε_i is the energy of scout j over D-dimension ($\varepsilon \in \{-1,1\}$), η_i is the step size of scout j ($\eta \in \{0, (0.001 * Ub)\}$) and ζ is the scouting constant. The scout location update was modelled using some attributes (energy and walking gait) of the human movement and energy efficiency model proposed in [16].

After updating the scouts locations, their finesses are evaluated again using Equation (4). This is followed by sorting and selection of best scout location until maximum scouting rate (α) is reached. Equation (6) is used to prevent the pastoralist from going outside the search space.

$$S'_i = \begin{cases} max(S'_i, L_b), \text{ if } S'_i < L_b \\ min(S'_i, U_b), \text{ if } S'_i > U_b \end{cases} \quad (6)$$

2.2.3 Camp Selection and Camping

Selection of the best location for camping S_{Gbest} is obtained by sorting and selecting the best scout in terms of their fitness after completing the maximum scouting iteration. The kth pastoralist P_K is initialized at camp C (where $C = S_{Gbest}$) using Equation (7).

$$P_K = C \quad (7)$$

2.2.4 Herding

The fitness of the kth pastoralist is evaluated using Equation (8) during herding. This is followed by sorting and selection of the best pastoralist P_{best}.

$$F(P_K) = FF(P_K) \quad (8)$$

2.2.5 Splitting

Each pastoralist split to different locations within the same camp until splitting rate (β) is maximum using Equation (9) which also follows modification of [16].

$$P'_K = P_{best} + (rand(0, r') * \varepsilon_k * \eta_k \quad (9)$$

Where P'_K is the kth pastoralist new location, P_{best} is the best pastoralist so far, $rand(0, r')$ is a random between 0 to r, r is the camp radius, ε_k is the energy of the kth pastoralist over D-dimension ($\varepsilon \in \{-1,1\}$) and η_k is the step size of the kth pastoralist ($\eta \in \{0, (0.001 * Ub)\}$). Thereafter, the fitness of the kth pastoralist is evaluated, using Equation (10) followed by sorting and selection of new best pastoralist P'_{best}. For each split, the camp radius is reduced using Equation (11).

$$F(P'_K) = FF(P'_K) \quad (10)$$

$$r'' = r'/nP \quad (11)$$

Where, r′′ is the camp radius of current iteration, and r′ is the camp radius of previous iteration.

2.2.6 Merging

During merging, the best location within the camp is updated by comparing the all pastoralist best locations using Equation (12).

$$C_{best,v} = \begin{cases} P_{best}, \text{ if } P_{best} < P'_{best} \\ P'_{best}, \text{ otherwise} \end{cases} \quad (12)$$

Where, $C_{best,v}$ is the camp best location (that is the best pastoralist within the camp) at the vth splitting rate, v ∈ [1: β]. If all locations within the camp have been exploited, the Global camp best pastoralist $G_{Cbest,z}$ is obtained by sorting all $C_{best,v}$ and selection of best camp pastoralist. Where, z: $z \in \{1: max\_iteration\}$ else, splits again to new locations by repeating the steps in sub-section 2.2.5 and 2.2.6.

If all maximum iteration not reached, the scouts' locations are updated again using Equation (3) followed by the processes in sections 2.2.2 to 2.2.6 are repeated. The Global best pastoralist G_{best} is obtained by sorting $Gc_{best,i}$ and selecting the global best pastoralist. The steps involved in POA is summarized in Figure 1.

i. *Start*
ii. *Initialize all POA parameters*
iii. *Select scout pastoralist randomly from number of pastoralists and initialize scout location using Equation (3)*
iv. *Evaluate the fitness of each scout, update scout locations and normalize scouts' locations within the search space until maximum scouting rate is reached (Equations (4, 5 and 6).*
v. *Select best camping location based and move pastoralist and herds to camp using Equation (7).*
vi. *Evaluate fitness of pastoralist and determine best pastoralist within a camp P_{best} using Equations (8).*
vii. *Split pastoralist to different locations within camp and evaluate fitness of each pastoralist using Equations (9 and 10).*
viii. *Repeat step vii until maximum splitting rate is reached. For each split, divide the current camp radius by the number of pastoralist using Equation 11.*
ix. *Update the best camp pastoralist C_{best} using Equation (12).*
x. *If all regions within the search space have not been explored (maximum iteration not reached), update scout location using Equation (3) repeat steps iv to ix and update the global camp best pastoralist Gc_{best}.*
xi. *Else, return the global best-found pastoralist $G_{best,}$*
xii. *Stop*

Figure 1: Proposed POA

3 EXPERIMENTAL RESULTS AND DISCUSSION

In this section, the experiments that were performed in order to evaluate the performance of the POA are presented. Two groups of test functions were selected to benchmark the proposed algorithm's performance, they are; Unimodal test functions (F1:F5) and the multimodal test functions (F6:F10). The dimension, range and the global optimum of each function is shown in Table 2 and their respective equations can be found in [17]. Unimodal functions have only a single global optimal solution. They are used to evaluate the algorithm exploitative capability, while multimodal test functions are used to evaluate algorithms exploration capability and ability to escape from getting stuck in local optima [8]. The algorithm was developed using MATLAB R2017a on a 64bit, 4Gig RAM computer.

Table 1: POA parameter settings

S/N	Parameter	Value
nP	Number of pastoralist	40
α	Scout rate	5
β	Split rate	30
r	Camp radius	0.01*(Ub)
Max-it	Maximun Iteration	1000
z	Number of runs	10

Table 2: Unimodal and Multi-modal Benchmark functions

Function ID	Function Name	Dim	Range	Global optimum
F1	Easom	2	[-100, 100]	-1
F2	Schaffer2	2	[-100, 100]	0
F3	Sphere	5	[-5.12, 5.12]	0
F4	Sum of different powers	5	[-1, 1]	0
F5	Sum Squares	5	[-10, 10]	0
F6	Ackley	5	[-32.768,32.768]	0
F7	Beale	2	[-4.5, 4.5]	0
F8	Bohachevsky	2	[-100, 100]	0
F9	Cross-in-Tray	2	[-10, 10]	-2.06261
F10	Dejong N.5	2	[-65.536, 65.536]	0.998

For each function, the best (minimum), worst (maximum) and average values were recorded after 10 runs each of 1000 iterations. Other paramters of the algorithm that were used for the experiments are shown in Table 1. The results obtained were compared with some similar and successful NI metaheuristic optimization algorithms (BBO [3], ABC [4] and ICA [6]).

3.1 Unimodal Test Functions Results

Table 2 shows the result obtained using POA compared to results obtained using BBO, ABC and ICA for unimodal test functions. From Table 3, it can be seen that POA obtained the global optimum value for F1 and F2 and the values obtained for F3 and F5 are the closest to the global optimum than those obtained with BBO, ABC and ICA. POA only performs less better than all the other algorithms on F4. Also, Figure 2 shows that the algorithm converges faster than others except for F1. This result is an indication of POA high exploitation capability guaranteed by the camping strategy of the pastoralist. The results also show that POA is very competitive and can be an alternative when solving problems of similar nature.

Table 3: Unimodal Test Function Results

Function	Performance	POA	BBO	ABC	ICA
F1	Best	-1	-1	-	-
	Worst	-1	-1	-	-
	Average	-1	-1	-	-
F2	Best	0	0	0	0
	Worst	0	5.5589e-4	0	0
	Average	0	1.1118e-4	0	0
F3	Best	1.1094e-106	3.2204e-19	1.2476e-29	1.6191e-53
	Worst	6.2387e-106	6.2858e-18	8.5357e-28	4.7341e-39
	Average	3.7436e-106	2.0781e-18	3.6343e-28	1.0822e-39
F4	Best	1.6592e-18	0	2.4822e-43	0

	Worst	1.5912e -17	0	1.7314e -40	0
	Average	4.8783e -18	0	3.5475e -41	0
F5	Best	1.5201e -102	1.6418e -19	7.5983e -28	6.1524e -48
	Worst	3.5312e -102	4.5778e -16	9.6766e -27	1.7365e -37
	Average	2.6457e -102	9.2557e -17	3.2322e -27	3.4767e -38

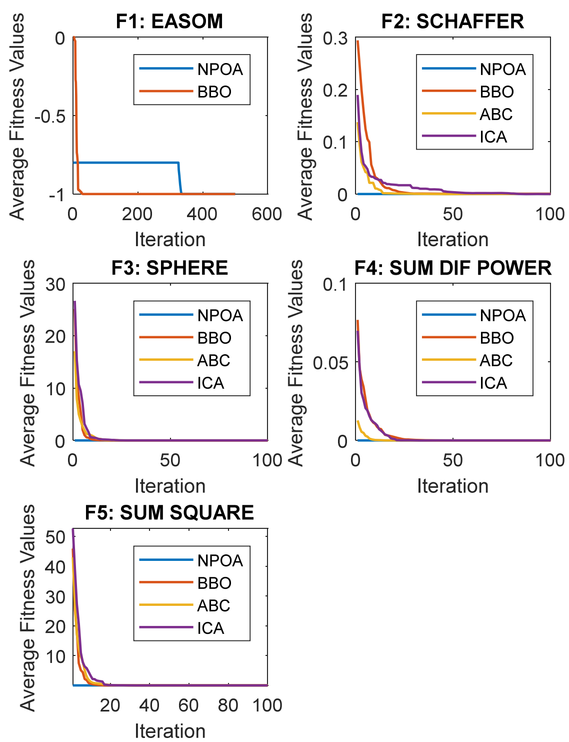

Figure 2: Convergence plot for Unimodal functions

3.2 Multimodal Test Function Results

Table 3 shows the result obtained using POA compared to results obtained using BBO, ABC and ICA for multimodal test functions. From Table 3, it can be seen that POA was able to obtained the global optimum for all the test functions. This is an indication of the algorithm high explorative ability and local optima avoidance. Also, the fast convergence rate of POA as shown in Figure 3 can be attributed to the effective scouting strategy of the pastoralist.

Table 3: Multi-modal Test Functions

Function	Performance	POA	BBO	ABC	ICA
F6	Best	-8.8818e-16	4.3991e-10	4.1108e-11	2.6645e-15
	Worst	2.6645e-15	5.0887e-9	1.0478e-10	6.2172e-15
	Average	-1.7764e-16	2.2748e-9	6.4982e-11	4.7962e-15
F7	Best	0	4.6577e-8	2.0226e-13	2.7325e-21
	Worst	0	3.3385e-6	1.1265e-11	1.4937e-11
	Average	0	1.1656e-6	1138e-12	3.4945e-12
F8	Best	0	0	-	0
	Worst	0	0.2183	-	0
	Average	0	0.0873	-	0
F9	Best	-2.0626	-2.0626	-2.0626	-2.0626
	Worst	-2.0626	-2.0626	-2.0626	-2.0626
	Average	-2.0626	-2.0626	-2.0626	-2.0626
F10	Best	0.998	0.998	0.998	0.998
	Worst	0.998	5.9288	0.998	0.998
	Average	0.998	2.7786	0.998	0.998

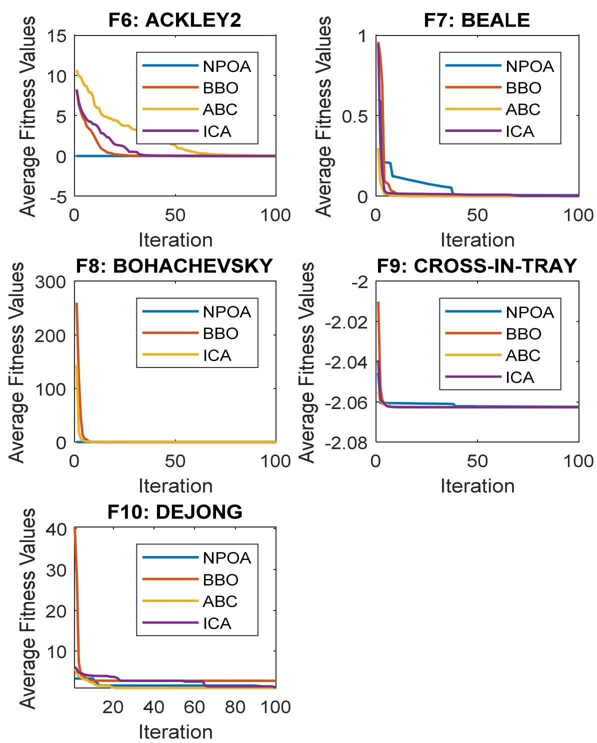

Figure 3: Convergence plot for Multimodal functions

3.3 Statistical Test Results

Table 4 presents the Wilcoxon rank sum nonparametric statistical test results that show how significant the obtained results are using a 5% (0.05) significance level [8]. The result indicated that there is no evidence (h = 0) to reject the null hypothesis of equal median between the observed and test samples at 5% confidence level. With P-Vlaue of 0.5715, POA's results for all functions is highly significant (closer to the global optimum) followed by BBO (0.2577), ICA (0.1828) and ABC (0.0951).

Table 4: Wilcoxon Rank Sum Test Results

ALGORITHM	*P-Value*	*h*
POA	0.5715	0
BBO	0.2577	0
ABC	0.0951	0
ICA	0.1828	0

4 CONCLUSION AND RECOMMENDATION

A novel nature-inspired metaheuristic optimization algorithm that is inspired by the herding strategies of nomadic pastoralist is proposed in this paper. The performance of the algorithm was evaluated by benchmarking it on 10 unimodal and multimodal benchmark test functions. The results show that POA has high exploitation and exploration abilities with high convergence speed. When compared with other popular nature-inspired optimization algorithms, like BBO, ABC and ICA, the proposed algorithm outperforms all of the algorithms in most cases and provides competitive result in all cases. From the results of this study, it can be concluded that for the proposed POA:

i. Exploration was guaranteed by scouting with longer step size.
ii. Exploitation was guaranteed by camping with a shorter step size.
iii. Local optima avoidance was guaranteed by splitting and merging within the camps.

For future studies using the proposed algorithm, it is recommended that;

i. Several other benchmark functions (unimodal, multimodal and composite) should be tested to evaluate the algorithm ability to balance between exploration and exploitation.
ii. Compare the results with those obtained from other popular population-based OA like Particle Swarm Optimization (PSO), Genetic Algorithm (GA).
iii. Explore and model more nomadic Pastoralist strategies to improve the algorithm performance.
iv. Apply the algorithm to solve real-world optimization problems.
v. Investige other movement strategies like the correlated random walk and levy flight which could improve the algorithm performance.

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