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Ant Lion Optimization: Variants, Hybrids, and Applications

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ABSTRACT Ant Lion Optimizer (ALO) is a recent novel algorithm developed in the literature that simulates the foraging behavior of a Ant lions. Recently, it has been applied to a huge number of optimization problems. It has many advantages: easy, scalable, flexible, and have a great balance between exploration and exploitation. In this comprehensive study, many publications using ALO have been collected and summarized. Firstly, we introduce an introduction about ALO. Secondly, we categorized the recent versions of ALO into 3 Categories mainly Modified, Hybrid and Multi-Objective. we also introduce the applications in which ALO has been applied such as power, Machine Learning, Image processing problems, Civil Engineering, Medical, etc. The review paper is ended by giving a conclusion of the main ALO foundations and providing some suggestions & possible future directions that can be investigated.

INDEX TERMS Ant lion optimizer, antlion, ALO, swarm intelligence, SI, meta-heuristics, optimization, nature-inspired algorithms.

I. INTRODUCTION

Optimization refers to the process of finding the optimal solution (min or max value) from a set of possible solutions (Search Space). It's everywhere and almost in every branch of science, Technology, and Engineering: from data mining to business planning, from computational intelligence to industrial application and from bioinformatics to Computer Science. In reality, we are always trying to minimize cost, money, and time and maximize performance and profit. Optimization problem can be defined using objective function f , a vector of variable X and a vector of constraints C as illustrated in equation 1.

$$\min_{x \in R^n} \text{ subject to } \begin{cases} C_i(x) = 0 & i \in E \\ C_i(x) \leq 0 & i \in I \end{cases} \quad (1)$$

where R , I and E stand for Real numbers domain, equalities, and inequalities respectively. Multi-objective optimization problem is one which have more than one objective to be optimized. Unfortunately, optimization problems are often complex since it belong to Non-deterministic polynomial time (NP-hard) and the mathematical techniques failed to solve it.

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In Literature, there are many meta-heuristic algorithms inspired from nature to solve these complicated problems. Here, we can classify meta-heuristic algorithms to the following groups as shown in Figure 1

- Evolutionary Algorithm
- Physics-based
- Chemistry-based
- Math-based
- Music-based
- Sport-based
- Plant-based
- Swarm-based
- Human-based.

Nowadays, Swarm Intelligence (SI) and bio-inspired algorithms are one of the hottest topics. Swarm Intelligence algorithms simulate the natural swarms or communities or systems such as schools of fish, birds swarms, bacterial growth, insects colonies, and animal herds [1] In the last two decades, SI have become more popular and its algorithm has gained huge popularity and attention. Swarm-based applications have got wide acceptance. This due to its great advantage like its flexibility, versatility, simplicity and avoiding local optima.

Literature has a large number of metaheuristics algorithm such as Particle Swarm Optimization [2] proposed by

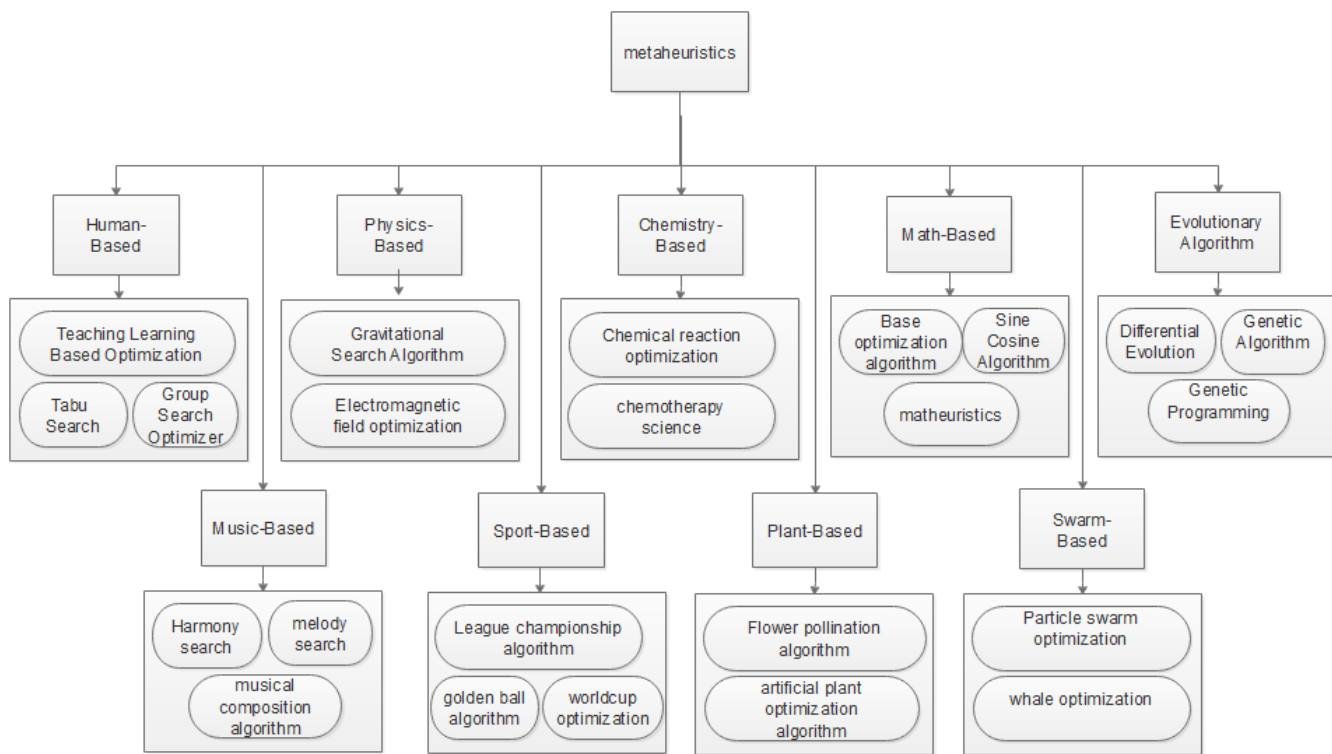


FIGURE 1. Classification of meta-heuristic algorithms.

Kennedy and Eberhart in 1995, Ant Colony Optimization [3] by Dorigo, Artificial Bee Colony(ABC) [4], [5] by Karaboga in 2005, Simulated Annealing [6] by Kirkpatrick *et al.*, Krill Herd algorithm [7] by Gandomi and Alavi, Cuckoo Search [8], Harmony Search [9], Firefly Algorithm [10], Chicken Swarm optimization(CSO) [11], Grey wolf optimizer [12] and The whale Optimization Algorithm [13] inspired by Mirjalili and Lewis. Here, the majority of the most famous algorithms as shown in Table 1.

In 2015, Mirjalili proposed a novel optimization algorithm called Ant Lion Optimizer [14] which simulate the foraging behaviors of Ant lion in nature.

In this work, A comprehensive review of the Ant lion optimization algorithm has been carried out. A statistical analysis has been performed to show how the scientist/researchers are attracted to ALO and how they are motivated to apply it to different real-world problems. All variants of ALO have been collected and summarized.

This paper is organized as follow, In section 2, we introduce our review methodology. Both the standard ALO algorithm and its variants have been illustrated and discussed in section 3 and 4 respectively. In section 5, we introduce the applications in which ALO has been applied in many fields such as power, computer science, medical applications, wireless network, control engineering, and others. An assessment and evaluation of ALO is done in section 6. Some concluding remarks and suggestion for further work are presented in Section 7.

II. REVIEW METHODOLOGY AND ANALYSIS

A. THE METHODOLOGY APPROACH

The main objective of this review is to make a comprehensive study of all aspects of ALO algorithm, and how the scholars are encouraged and motivated to apply it in different applications. In addition, this review will highlight the strengths of algorithm and the improvements suggested in the literature to overcome the algorithm weakness. Furthermore, the review will refer to all of the previous research that discussed the ALO by referring to the various well-regarded publishers such as Elsevier, Springer, IEEE, and others. Figure 2 shows the number of publications which are distributed based on the publisher of the ALO-related articles. Also, Figure 3 show the distribution of Number of publication per year since the appearance of the algorithm. Reviews are very important, it make the user up-to-date to the improvements and upgrades for a specific topic. Literature has a lot of reviews in bio-inspiring algorithms such as Cuckoo search in [103], krill herd in [104], Firefly Algorithm [105], Gravitational Search Algorithm [106], Artificial Bee Colony in [107], Grey Wolf Optimizer [108] and all sports inspired algorithms in [109]. In Table 2 we list top 10 Journals with the greatest number of papers works on ALO.

B. ALO RESEARCH TREND

Ant Lion Optimizer(ALO) has received a huge interest and significant acceptance since it has been published

TABLE 1. List of some meta-heuristic algorithms (1975-2020).

No	Algorithm	Year	Author
1	Genetic Algorithm (GA) [15]	1975	Holland
2	Scatter Search (SS) [16]	1977	Glover
3	Simulated Annealing (SA) [6]	1983	Kirkpatrick et al.
4	Tabu Search (TS) [17]	1986	Glover
5	Artificial Immune System (AIS) [18]	1986	Farmer et al.
6	Memetic Algorithm (MA) [19]	1989	Moscato
7	Particle Swarm Optimization (PSO) [2]	1995	Kennedy and Eberhart
8	Cross Entropy Method (CMS) [20]	1997	Rubinstein
9	Differential Search Algorithm (DSA) [21]	1997	
10	Harmony Search (HS) [9]	2001	Geem et al
11	Artificial Fish-Swarm Algorithm (AFSA) [22]	2003	li
12	Bees Optimization (BO) [23]	2004	Nakrani and Tovey
13	Glow-worm Swarm Optimization (GSO) [24]	2005	
14	Artificial Bee Colony (ABC) [4], [5]	2005	Karaboga
15	Glow worm Swarm Optimization (GSO) [25]	2005	Krishnanad and Ghose
16	Cat Swarm Optimization [26]	2006	Chu et al.
17	Termite Algorithm [27]	2006	Roth
18	Monkey Search (MS) [28]	2007	Mucherino and Seref
19	Cockroach Swarm Optimization [29]	2010	ZhaoHui and HaiYan
20	Firefly Algorithm (FA) [10]	2008	X. Yang
21	Metaheuristics [30]	2009	Voss et al.
22	League Championship Algorithm (LCA) [31]	2009	Kashan
23	Group Search Optimizer [32]	2009	He et al.
24	Cuckoo Search (CS) [8]	2009	Gandomi et al.
25	Gravitational Search Algorithm (GSA) [33]	2009	Rashedi et al.
26	Virus Optimization Algorithm (VOA) [34]	2009	Juarez et al.
27	Bat Algorithm (BA) [35]	2010	Yang
28	Chemical Reaction Optimization (CRO) [36]	2010	Xu et al.
29	Hunting Search [37]	2010	R. Oftadeh et al.
30	Spiral Optimization (SO) [38]	2011	Tamura and Yasuda
31	Brain Storm Optimization (BSO) [39]	2011	Shi
32	Ant Colony Optimization (ACO) [3]	2011	Dorigo
33	Teaching Learning Based Optimization (TLBO) [40]	2012	Rao et al.
34	Ray Optimization [41]	2012	Kaveh and Khayatatzad
35	Football Optimization Algorithm [42]	2012	Hatamzadeh and Khayyambashi
36	Flower Pollination Algorithm (FPA) [43]	2012	X. Yang
37	Krill Herd (KH) algorithm [7]	2012	Gandomi and Alavi
38	Mine Blast Algorithm [44]	2013	Sadollah et al.
39	Magnetic Charged System Search [45]	2013	Kaveh
40	Soccer Game Optimization [46]	2013	Purnomo and Wee
41	Dolphin Echolocation [47]	2013	A.Kaveh and N.Farhoudi
42	Interior Search Algorithm (ISA) [48]	2014	Amir H.Gandomi
43	Soccer League Optimization [49]	2014	Moosaviana and Roodsari
44	Golden Ball [50]	2014	E. Osaba et al.
45	Chicken Swarm Optimization(CSO) [11]	2014	Xianbing Meng et al.
46	Grey Wolf Optimizer [12]	2014	S. Mirjalili et al.
47	Exchange Market Algorithm [51]	2014	Ghorbani and Babaei
48	Crisscross Optimization Algorithm [52]	2014	An-boMeng et al.
49	Competition over Resources [53]	2014	Sina Mohseni et al.
50	Symbiotic Organisms Search [54]	2014	Cheng and Prayogo
51	Bird Swarm Algorithm [55]	2015	Meng et al.

TABLE 1. (Continued.) List of some meta-heuristic algorithms (1975-2020).

No	Algorithm	Year	Author
52	Social Spider Algorithm [56]	2015	Yu and Li
53	The Ant Lion Optimizer [14]	2015	S. Mirjalili
54	Artificial Algae Algorithm [57]	2015	AliUymaz et al.
55	Moth-Flame Optimization [58]	2015	S. Mirjalili
56	Elephant Herding Optimization [59]	2015	Gai-Ge Wang et al.
57	Earthworm Optimization Algorithm [60]	2015	Gai-Ge Wang et al.
58	Monarch Butterfly Optimization [61]	2015	Gai-Ge Wang et al.
59	Yin-Yang-Pair Optimization (YYPO) [62]	2016	Punnathanam and Kotecha
60	Passing Vehicle Search (PVS) [63]	2016	Savsani and Savsani
61	Red Deer Algorithm (RDA) [64]	2016	Fard and Keshteli
62	World Cup Optimization [65]	2016	N Razmjooy et al.
63	Football Game Algorithm [66]	2016	Fadakar and Ebrahimi
64	Shark Smell Optimization [67]	2016	Abedinia
65	Dolphin Swarm Optimization [68]	2016	Tian-qi Wu et al
66	Crow Search Algorithm [69]	2016	Alireza Askarzadeh
67	Multi-Verse Optimizer [70]	2016	Seyedali Mirjalili et al.
68	Lion Optimization Algorithm [71]	2016	Yazdani and Jolai
69	The Whale Optimization Algorithm [13]	2016	Mirjalili and Lewis
70	Sperm Whale Algorithm [72]	2016	A.Ebrahimi and E.Khamehchi
71	Dragonfly Algorithm [73]	2016	Seyedali Mirjalili
72	Sine Cosine Algorithm [74]	2016	S. Mirjalili
73	Water Evaporation Optimization [75]	2016	A.Kaveh et al.
74	Competitive Optimization Algorithms [76]	2016	Sharafi et al.
75	Galactic Swarm Optimization [77]	2016	Muthiah-Nakarajan and Noel
76	Electromagnetic Field Optimization [78]	2016	Abedinpourshotorban et al.
77	Butterfly-inspired algorithm [79]	2016	Qi et al.
78	Lightning Attachment Procedure Optimization [80]	2017	
79	Electro-Search algorithm [81]	2017	Tabaria and Ahmad
80	Kidney-inspired algorithm [82]	2017	Najmeh et al.
81	Most Valuable Player Algorithm [83]	2017	Gerkey et al.
82	Selfish Herds [84]	2017	Fausto et al.
83	Spotted Hyena Optimizer [85]	2017	Dhiman and Kaur
84	Chemotherapy Science [86]	2017	Salmani and Eshghi
85	Grasshopper Optimisation algorithm [87]	2017	Shahrzad Saremi et al.
86	Salp Swarm Algorithm [88]	2017	Mirjalili et al.
87	Thermal Exchange Optimization [89]	2017	Kaveh and Dadras
88	Volleyball Premier League Algorithm [90]	2018	Moghdani and Salimifard
89	CFA optimizer [91]	2018	Ghasemi et al.
90	The Social Engineering Optimizer [92]	2018	A. Fathollahi-Fard et al.
91	Car Tracking Optimization Algorithm [93]	2018	Chen et al.
92	Owl Search Algorithm [94]	2018	Jain et al.
93	Tree Growth Algorithm (TGA) [95]	2018	Cheraghalipour et al.
94	Squirrel Search Algorithm [96]	2019	Jain et al.
95	Butterfly Optimization Algorithm [97]	2019	Arora and Singh
96	Henry Gas Solubility Optimization [98]	2019	Hashim et al.
97	Equilibrium Optimizer [99]	2019	Faramarzi et al.
98	Bald Eagle Search [100]	2019	Alsattar et al.
99	Harris Hawks Optimization [101]	2019	Heidari et al.
100	Nuclear Reaction Optimization [102]	2019	Wei et al.

Number of ALO Publications per publisher

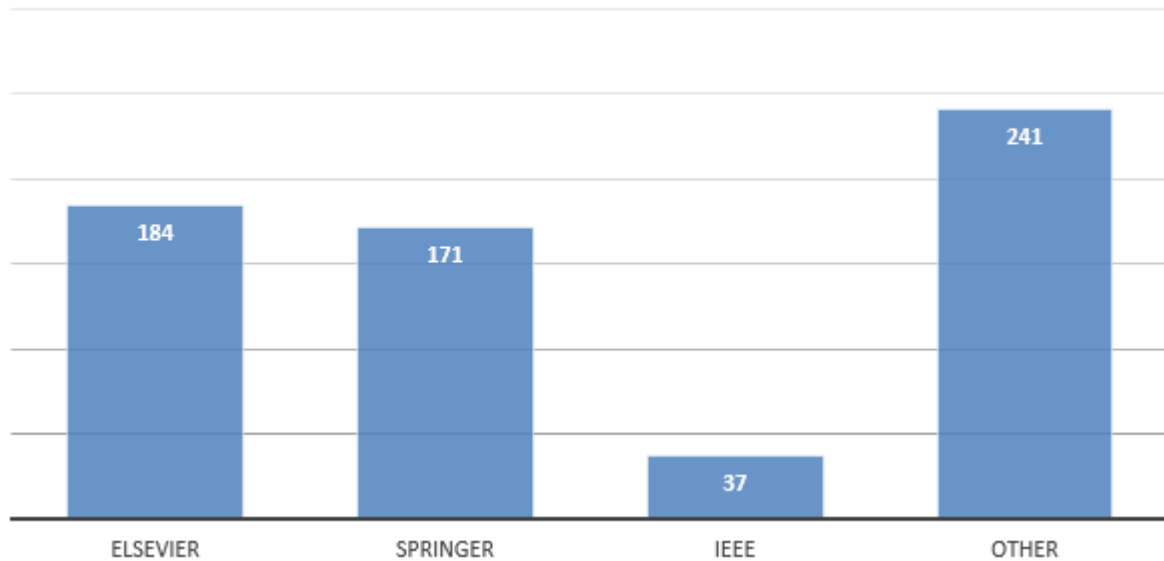


FIGURE 2. Number of publications of ALO per publisher.

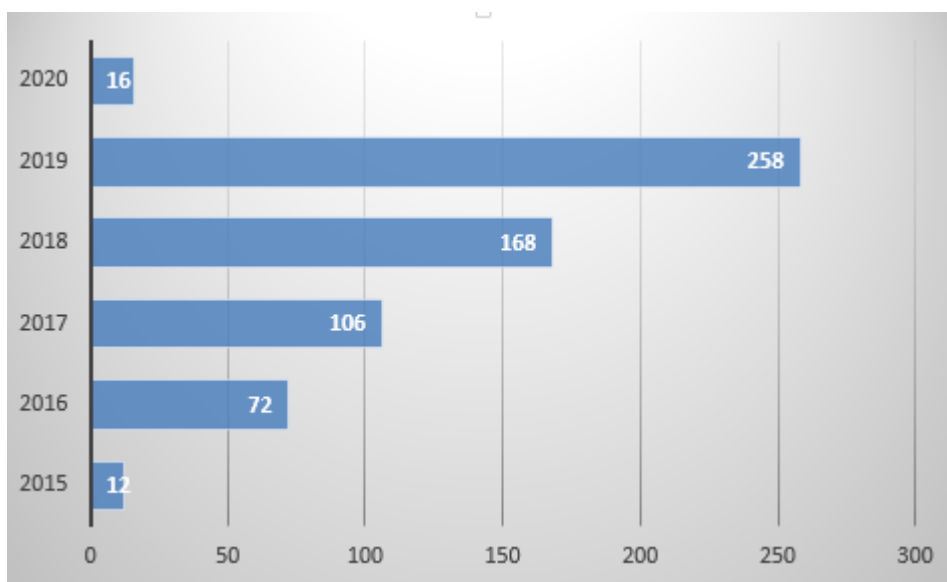


FIGURE 3. Number of publications of ALO per Year.

in 2015. The original paper according to google scholar (https://scholar.google.co.uk/scholar?hl=en&as_sdt=0%2C5&q=The+ant+lion+optimizer&btnG=) has been cited 942 time (accessed on 16th March 2020), 419 were published in high ranked journals, 96 in conferences, and 14 Book chapters. Due to its advantages the original paper was selected one of the tops highly ranked papers in both web of Science¹

¹https://apps.webofknowledge.com/full_record.do?product=WOS&search_mode=GeneralSearch&qid=2&SID=F6qZlrsgj1HpQ5yRMAu&page=1&doc=1&cacheurlFromRightClick=no

and Scopus.² It's also one of the most downloaded and cited paper in advances in engineering software.^{3,4}

Also, it should be mentioned here, that the Multi-Objective MFO paper, with title “Multi-objective ant lion optimizer: a multi-objective optimization algorithm for solving engineering problems” (Applied Intelligence, 2017, 46(1):79-95),

²<https://www.scopus.com/record/pubmetrics.uri?eid=2-s2.0-84923355494&origin=recordpage>

³<https://www.journals.elsevier.com/advances-in-engineering-software/most-downloaded-articles>

⁴<https://www.journals.elsevier.com/advances-in-engineering-software/most-cited-articles>

TABLE 2. The top 10 journals with the largest number of the papers on ALO.

Rank	Journals	Number of papers
1	Neural Computing And Applications	36
2	Applied Soft Computing Journal	30
3	IEEE Access	19
4	Soft Computing	17
5	Knowledge Based Systems	16
5	Advances In Intelligent Systems And Computing	16
5	Expert Systems With Applications	16
8	Applied Intelligence	10
9	Engineering Application of Artificial Intelligence	8
10	Advances In Engineering Software	7

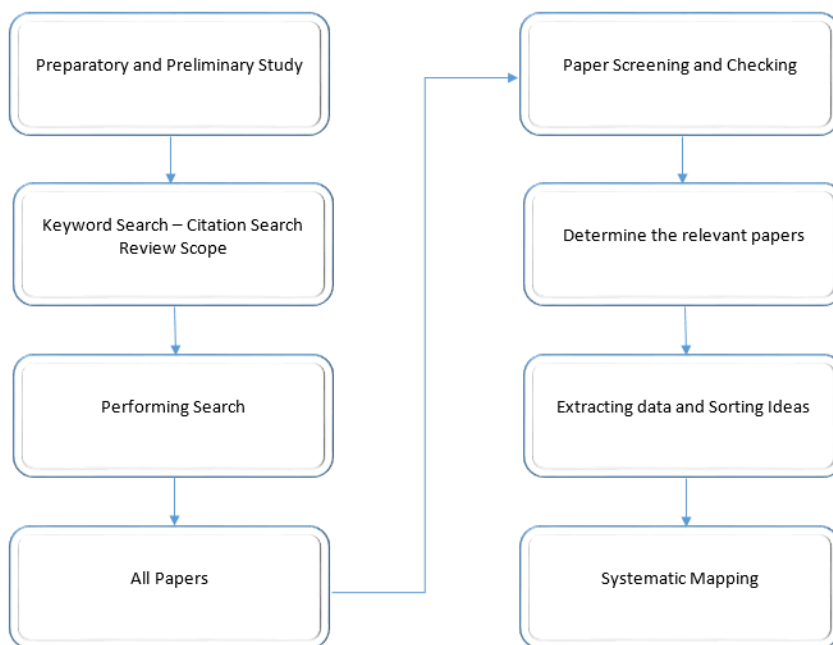


FIGURE 4. Review methodology.

was selected as a hot paper from Web of Science⁵ and from 1% highly selected paper from Scopus⁶ In this study, we follow steps as illustrated in Figure 4. First, we make preparatory Study, then we search on papers which have cited the original paper to determine keyword to use it on search. Second, we do skimming and scanning techniques to determine relevant papers. Then, we screening and checking paper to extract data. After that, we extract data and sorting ideas.

III. STANDARD OF ANT LION OPTIMIZER

A. ALO

In this section, we present the basics of ALO Algorithm by describing its main components such as inspiration, its mathematical model, and how it deals with exploration.

⁵https://apps.webofknowledge.com/full_record.do?product=WOS&search_mode=GeneralSearch&qid=6&SID=F6qZlrsgj1HpQ5yRMAu&page=1&doc=3

⁶<https://www.scopus.com/record/pubmetrics.uri?eid=2-s2.0-84979263751&origin=recordpage>

1) BIOLOGICAL FOUNDATION

Antlion is the insect species predatory which belongs to Myrmeleontidae family. In their larval period(2.5-3 years), they usually eat ants. Antlion digs a hole with a cone shape using its jaw. Then it hides in the bottom of the cone and waits. when an ant trap into the hole, it begins throwing sand towards the trap in order to bury the prey. After catching the prey and consumed it, Antlion throw the prey’ leftover outside the trap as illustrated in figure 5.

2) MATHEMATICAL MODEL AND OPTIMIZATION ALGORITHM

To model the stochastic move of ants in the search space, a random walk is used as follows:

$$X(t) = [0, \text{cumsum}(2r(t_1) - 1), \text{cumsum}(2r(t_2) - 1), \dots, \text{cumsum}(2r(t_n) - 1)] \quad (2)$$

where $X(t)$ represent ant random walk, n is the maximum number of iteration, t represent the current iteration, cumsum

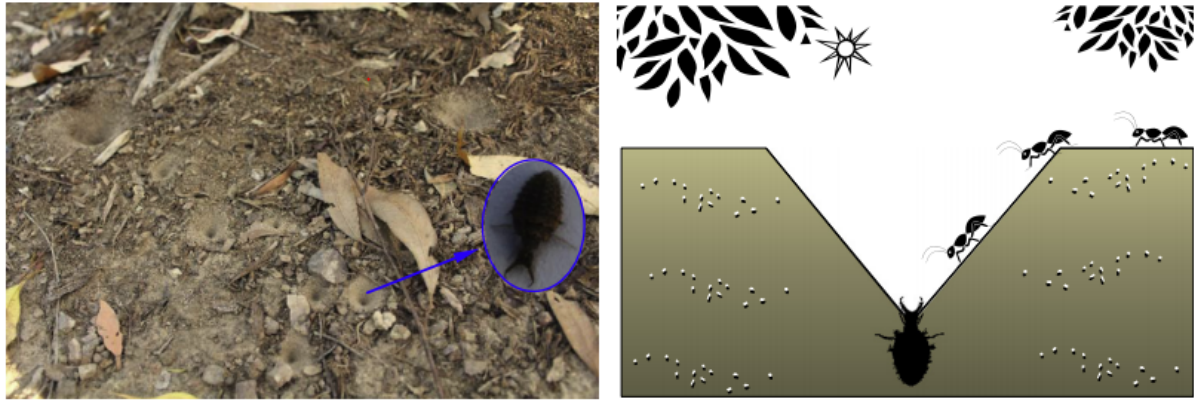


FIGURE 5. Cone-shaped traps and hunting behaviour of antlions [14].

refers to the cumulative sum, and $r(t)$ refers to a stochastic function which is defined as follows:

$$r(t) = \begin{cases} 1 & \text{rand} > 0.5 \\ 0 & \text{otherwise} \end{cases} \quad (3)$$

where rand is a random number in the interval of [0, 1]. Ants and antlions positions is given by the following matrices Eq. 4, and Eq. 5 respectively.

$$M_{Ant} = \begin{bmatrix} A_{1,1} & A_{1,2} & \dots & \dots & A_{1,d} \\ A_{2,1} & A_{2,2} & \dots & \dots & A_{2,d} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ A_{n,1} & A_{n,2} & \dots & \dots & A_{n,d} \end{bmatrix} \quad (4)$$

$$M_{Antlion} = \begin{bmatrix} AL_{1,1} & AL_{1,2} & \dots & \dots & AL_{1,d} \\ AL_{2,1} & AL_{2,2} & \dots & \dots & AL_{2,d} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ AL_{n,1} & AL_{n,2} & \dots & \dots & AL_{n,d} \end{bmatrix} \quad (5)$$

where M_{Ant} is a matrix that saves ant position, $M_{Antlion}$ is a matrix that saves antlion position, $A_{i,j}$ gives the i -th ant value at the j -th dimension, n is the number of ants, and d is the number of dimensions To evaluate each ant and antlion, a fitness function is used and the results is stored in matrix as shown in Eq. 6 and Eq. 7.

$$M_{OA} = \begin{bmatrix} f([A_{1,1}, A_{1,2}, \dots, A_{1,d}]) \\ f([A_{2,1}, A_{2,2}, \dots, A_{2,d}]) \\ \vdots \\ \vdots \\ \vdots \\ f([A_{n,1}, A_{n,2}, \dots, A_{n,d}]) \end{bmatrix} \quad (6)$$

$$M_{OAL} = \begin{bmatrix} f([AL_{1,1}, AL_{1,2}, \dots, AL_{1,d}]) \\ f([AL_{2,1}, AL_{2,2}, \dots, AL_{2,d}]) \\ \vdots \\ \vdots \\ \vdots \\ f([AL_{n,1}, AL_{n,2}, \dots, AL_{n,d}]) \end{bmatrix} \quad i \quad (7)$$

where M_{OA} is a matrix that saves ant fitness, M_{OAL} is a matrix that saves antlion fitness, $A_{i,j}$ gives the i -th ant value at the j -th dimension, n is the number of ants, and f is the objective function.

To keep ants random walk inside the search space, Equation 8 is used to normalize ant position.

$$X_i^t = \frac{(X_i^t - a_i)(d_i^t - c_i^t)}{b_i - a_i} + c_i^t \quad (8)$$

where a_i, b_i is the minimum and maximum random walk of i -th variable respectively, c_i^t, d_i^t is the minimum and maximum of i -th variable at iteration t .

In order to model the behaviours of antlions' trap, the following equations are introduced.

$$c_i^t = \text{Antlion}_i^t + c^t \quad (9)$$

$$d_i^t = \text{Antlion}_i^t + d^t \quad (10)$$

$$c^t = \frac{c^t}{I} \quad (11)$$

$$d^t = \frac{d^t}{I} \quad (12)$$

where c^t, d^t is the minimum and maximum of all variables at t -th iteration respectively, c_i^t, d_i^t is the minimum and maximum of all variables for i -th ant respectively, Antlion_i^t shows the j -th antlion position at t -th iteration, and I is the sliding ratio changes as in the following equation.

$$I = \begin{cases} 1 + 10^6 \text{iter}/\text{MaxIter} & \text{if } 0.95\text{MaxIter} < \text{iter} < \text{MaxIter} \\ 1 + 10^5 \text{iter}/\text{MaxIter} & \text{if } 0.90\text{MaxIter} < \text{iter} < 0.95\text{MaxIter} \\ 1 + 10^4 \text{iter}/\text{MaxIter} & \text{if } 0.75\text{MaxIter} < \text{iter} < 0.90\text{MaxIter} \\ 1 + 10^3 \text{iter}/\text{MaxIter} & \text{if } 0.5\text{MaxIter} < \text{iter} < 0.75\text{MaxIter} \\ 1 + 10^2 \text{iter}/\text{MaxIter} & \text{if } 0.1\text{MaxIter} < \text{iter} < 0.50\text{MaxIter} \\ 1 & \text{otherwise} \end{cases} \quad (13)$$

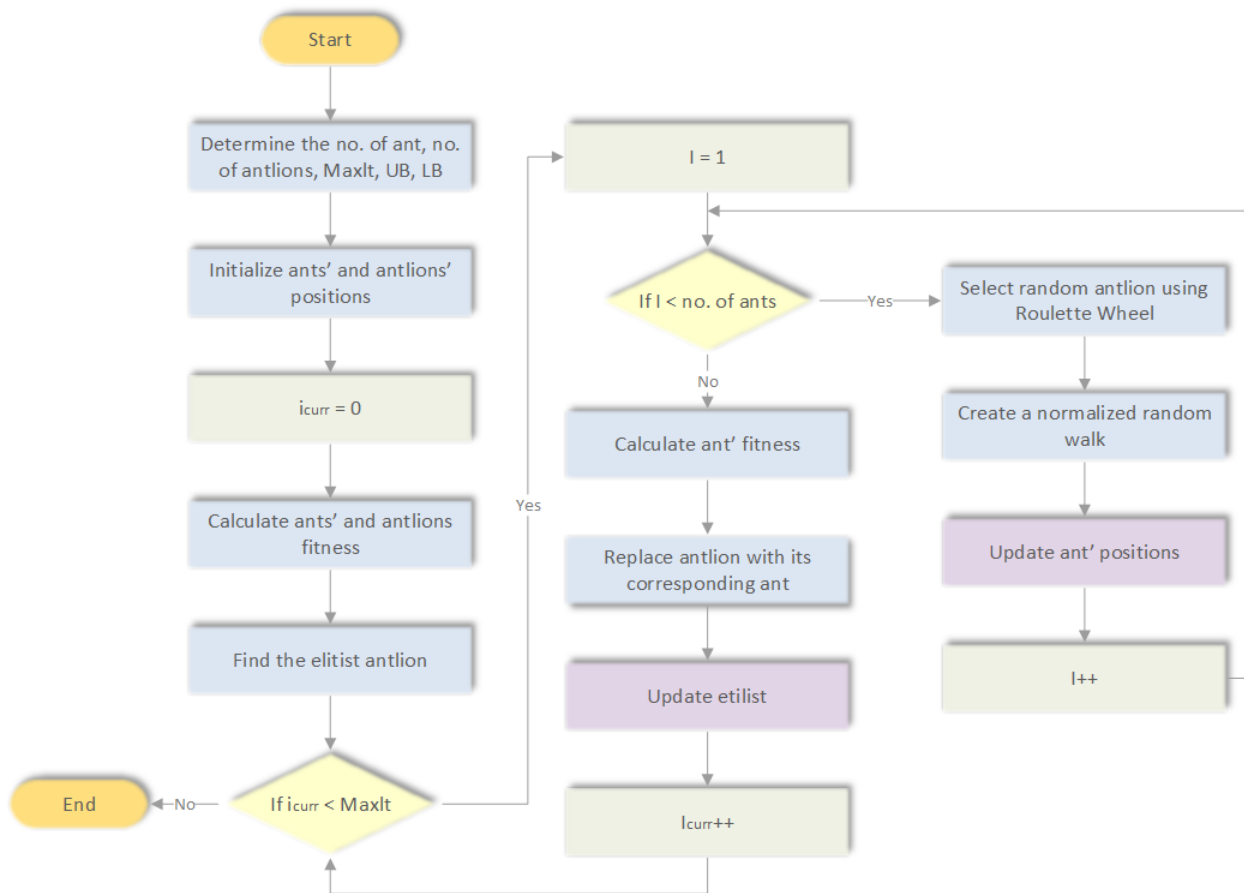


FIGURE 6. Flow chart.

The best solution (antlion position) termed as R_E^t is saved and the fittest antlion affect all ants movements. R_A^t is an antlion selected by roulette wheel as in the following equation:

$$Ant_i^t = \frac{R_A^t + R_E^t}{2} \quad (14)$$

To model the final hunting stage when the ant is pulled inside the sand and being consumed. Then, antlion update its position according to the next equation:

$$Antlion_i^t = Ant_i^t \quad \text{if} \quad (Ant_i^t) < Antlion_i^t \quad (15)$$

The general pseudo-code steps of ALO are presented in Algorithm 1 and the flow chart are presented in Figure 6.

IV. DIFFERENT METHODS OF (ALO)

A. MODIFIED ALO

In literature, there are many enhancement done on ALO. Table 3 lists all these modifications.

1) BINARY ALO

Emary et al. in [110] proposed 3 binary variant of ALO using 2 approaches. The first one makes the original ALO operators binary one, but in the second approach authors

Algorithm 1 Ant Lion Optimization Algorithm

Input: Number of antlions, Number of ants, fitness function, MaxIter.

Output: the position of the elitist antlion and its fitness value.

Initialize the position of antlions, and ants randomly.

Calculate each antlion fitness value.

Find the best antlion.

while stopping criteria not meet to **do**

Select antlion by using roulette wheel to build a trap.

Slide ants randomly in a trap.

Create a random walk for each ant around the elitist antlion and normalize it.

Update the position of each ant by using the average of 2 random walks.

Calculate each ant fitness

Replace an antlion with it corresponding if its fitter

Update the elitist antlion

end while

squash the continuous steps using threshold function. They compared their results with many state-of-art algorithms i.e PSO, GA, BBA.

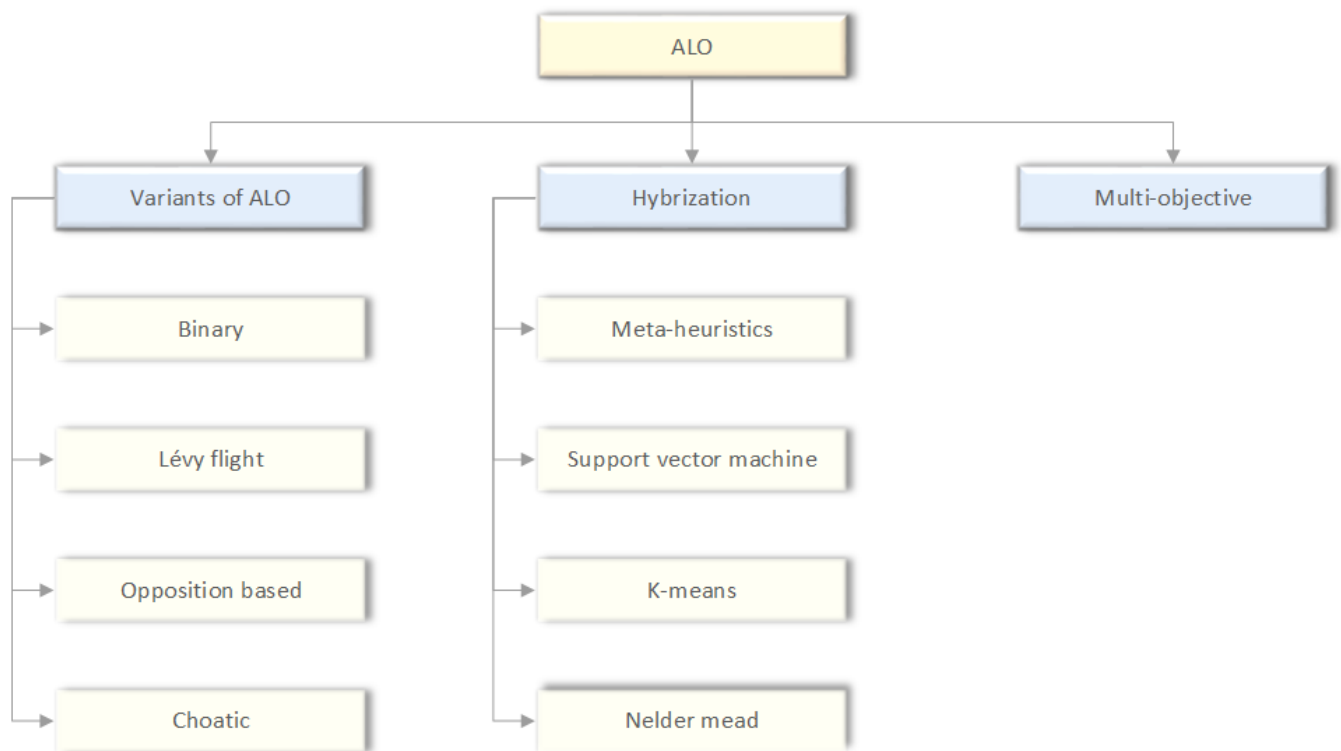


FIGURE 7. Different versions of ALO.

TABLE 3. Modified versions of ALO list.

Ref.	Version Name	Abb.	Authors
[110]	Binary AntLion Algorithm	bALO	Emary et al.
[111]	binary coded of ALO	BCALO	Manoharan et al.
[112]	Binary Ant Lion Optimisation	BALO	Jorquera et al.
[114]	improved Antlion optimization algorithm	IAO	Kumar et al.
[115]	improved Antlion optimization algorithm	IALO	Kılıç and Yüzgeç
[116]	improved Antlion optimization algorithm	IALOT	Kılıç and Yüzgeç
[117]	improved Antlion optimization algorithm	IALO	Toz
[119]	Novel Improved Antlion Optimization Algorithm	IALO	Li et al.
[122]	Improved Ant Lion Optimizer	IALO	Zhang et al.
[138]	Hybrid Ant Lion Optimization	HALO	Dwivedi and Balasubbareddy
[124]	Enhanced ALO	e-ALO	Subhashini and Satapathy
[130]	modified ALO	MALO	Wang et al.
[129]	Lévy Antlion Optimization	LALO	Emary and Zawbaa
[131]	Opposition-based Lévy flight ALO	OB-LF-ALO	Dinkar and Deep
[132]	Opposition based Laplacian ALO	OB-L-ALO	Dinkar and Deep
[133]	Accelerated Opposition-Based ALO	OB-ac-ALO	Dinkar and Deep
[134]	Opposition-based Cauchy distribution ALO	OB-C-ALO	Dinkar and Deep
[135]	chaotic version of ALO	CALO	Zawbaa et al.
[136]	quasi-oppositional chaotic ALO	QOCALO	Saha and Mukherjee
[137]	chaotic ALO	CALO	Tharwat and hassanien
[123]	Parallel Ant Lion Optimizer & Neural Network	PALONN	Manuel and Emayavaramban
[127]	Ant Lion Optimizer with Differential Mutation	ALO-DM	Hu et al.
[128]	ALO Tournament selection	TALO	Kılıç and Yüzgeç

Also, Manoharan *et al.* in [111] proposed a novel binary coded of ALO and apply it to solve Phasor Measurement Unit (PMU) placement model.

Another Binary ALO version is proposed by Jorquera *et al.* [112]. They tested and applied it to Set Covering Problem. In [113] Ye *et al.* tried to handle the structure of Artificial Neural Network (ANN) by Considering

it as a combinatorial Optimization problem. They assumed that the experimental results showed the effectiveness of their method for structural optimization of ANN.

2) IMPROVED ALO

In [114] Kumar *et al.* applied their improved version of ALO in maximizing power extraction from shaded PV panel in

seasons which are rainy. In their algorithm, which termed their algorithm IAO, they replace ant update equation eq. 14 which based on roulette wheel (RW) with a process based on rank basis which consist of 2 steps. 1) Sort all random walk in decreasing order and arrange them in queue. 2) Move, one by one, towards the antlions from higher rank to lower one.

In [115] Kılıç and Yüzgeç proposed another improvement of ALO by making some improvements in the selection process. The same authors in [116] proposed another version of ALO called IALOT by introducing some enhancement. 1) Replacing Roulette Wheel (RW) with tournament method. 2) Enhancing some mechanisms in the original ALO such as random walk, reproduction, ant sliding, elitism and selection method. 3) reducing running time. They compared the novel algorithm with 4 state-of-art algorithms namely PSO, ABC, SA and DE.

Toz in [117] proposed a new version of ALO called IALO by introducing new decreasing boundary instead of step-by-step decreasing for shrinking of the boundary. This new procedure is inspired by decrement of the VOA [118].

Also, Li *et al.* [119] proposed a novel version of ALO by replacing roulette wheel with new technique which classify antlions to 2 groups then, some novel equations are used to breakthrough steps to enhance diverse exploration and thorough exploitation in each group. In [120] Yu proposed an improved version of antlion by hybridizing ALO with Nelder-Mead algorithm and apply it to detect structural damage by improving weighted trace lasso regularization. **Kilic** *et al.* [121] introduced IALO algorithm by using the absolute value of fitness value before applying roulette wheel selection. In addition to the above enhancement, Zhang *et al.* in [122] showed another improved approach of ALO by integrating it chaotic mapping theory with initialization and random walk process.

In [123] Manuel and Emayavaramban proposed a Parallel Ant Lion Optimizer and Artificial Neural Network and applied it to the Micro Grid-Connected Power Flow Control. They argued that their ALO version offer several benefits: enhanced predicting capability, randomization, and degradation in complexity.

3) ENHANCED & MODIFIED ALO

Subhashini and Satapathy in [124] introduce an enhanced version of ALO (e-ALO) by modifying the original ALO. They apply a stochastic function to generate random number between [0,1] instead of uniform distribution function. Authors compared their results with PSO, SMS and BA. They also apply their algorithm to synthesis of Antenna Array.

In [125] Gupta *et al.* proposed a modified ALO version to improve the accuracy of thyroid diseases. Also, Ksiazek *et al.* [126] apply another enhanced version of ALO in Radiation heat transfer. In [127] Authors introduced an enhanced version of ALO called ALO-DM by combining differential mutation technique. They argued that this version

of ALO enhanced population diversity and obtain an effective and effective solution. In [128] Kılıçand Yüzgeç proposed a novel version of ALO called TALO based on tournament selection. They compared their new version with the classical ALO and many other versions (chaotic ALO and binary ALO) and applied it in solving quadratic assignment problem.

4) LÉVY ALO & OPPOSITION-BASED ALO

Emary and Zawbaa in [129] made a modification on the original ALO by using Lévy flight random walk instead of uniform distribution random one. They argued that their proposed algorithm (LALO) is cable of escaping local minima and is able to examine large search space. They apply LALO on feature selection using 21 dataset. The result is compared with GA, PSO and ALO.

In [130] Wang *et al.* develop a modified version of ALO (MALO) based on the original ALO and wavelet support vector machine and Lévy flight to avoid local optimum. They compared their results with state-of-art algorithms and test their novel algorithm in feature selection problem.

Dinkar and Deep in [131] proposed an enhanced version of ALO called OB-LF-ALO which based on Opposition-based Learning (OBL) and Lévy flight (LF). They replaced the uniform distribution with LF random walk in conjunction with OBL. OB-LF-ALO is tested on both constrained and unconstrained engineering problem.

The same authors in [132] proposed another version called OB-L-ALO to accelerate and enhance the native ALO by using 2 strategies: Laplace distribution is employed in random walk rather than uniform distribution besides OBL. They test the proposed algorithm using 27 benchmark function and give a comprehensive analysis of convergence curve, trajectories and data distribution using boxplot.

Also in [133], [134], the same authors introduced 2 new variant of ALO called OB-ac-ALO, and OB-C-ALO. The first algorithm is based on OBL and acceleration coefficient (ac), while the second use OBL besides Cauchy distribution. They apply the first algorithm to reduct the order of Time-Invariant Systems, and the second in clustering data.

5) CHAOTIC ALO

Zawbaa *et al.* [135] proposed a chaotic version of ALO (CALO). They evaluated the new algorithm using different chaotic maps and applied it to Feature Selection (FS) problem.

Saha and Mukherjee in [136] introduced a new version of ALO called (QOCALO) using quasi-oppositional chaotic method. In their proposed algorithm, the initialization of the first population is done using quasi-oppositional based learning (QOBL). Then the QOBL technique is embedded in the main search process. Also a chaotic local search is also employed in QOCALO algorithm.

Tharwat and hassanien in [137] proposed a novel chaotic ALO called (CALO) to optimize the parameter of support vector machine (SVM). They compared the novel algorithm

TABLE 4. Hybrid versions of ALO list.

Ref.	Version Name	Abb.	Authors
[139]	Hybrid Fuzzy C Means (FCM) and ALO	FCM-ALO	Parvathi and Rajeswari
[140]	hybrid algorithm ALO-Kmeans	ALO-Kmeans	Majhi and Biswal.
[142]	hybrid ant lion optimizer and Jaya algorithm	Hybrid ALO-Jaya	Aziz <i>et al.</i>
[120]	ant lion optimizer with improved Nelder-Mead	ALO-INM	Yu

TABLE 5. Multi-Objective versions of ALO list.

Ref.	Version Name	Abb.	Authors
[143]	a multi-objective version of ALO	(MOALO)	Mirjalili <i>et al.</i>
[144]	multi-objective version of modified ALO algorithm based on Tent Map	(MU-MOALO)	Dos <i>et al.</i>
[145]	multi-objective version of modified ALO algorithm based on Lozi Map	(MOALO)	Dos <i>et al.</i>
[146]	Multi-Objective ALO	(MOALO)	Hosseini <i>et al.</i>
[148]	Improved Multi-Objective ALO	(I-MOALO)	Mahanta <i>et al.</i>

with native ALO, Genetic Algorithm (GA), Particle Swarm Optimization (PSO), and Social Emotional Optimization Algorithm (SEOA).

B. HYBRID VARIANTS OF ALO

Table 4 shows the list of Hybrid versions applied to ALO. Parvathi and Rajeswari in [139] proposed a hybrid algorithm based on Fuzzy C Means (FCM) and ALO. They applied the new algorithm FCM-ALO in image segmentation.

Majhi and Biswal in [140] develop a hybrid algorithm ALO-Kmeans combines ALO with Kmeans to improve clustering. They argued that the novel algorithm is better than Kmeans and PSO-Kmeans.

In [141] Guo *et al.* hybridized ALO with Relevance Vector Machine (RVM) and Beveridge-Nelson decomposition method (BND) method. Their algorithm which is called BND-ALO-RVM forecaster is used to make accurate wind forecasting method. To verify their methods, authors compared results with single RVM, BND-RVM, ALO-RVM, Regression neural network based on wavelet transform WT-GRNN. Also, Dwivedi and Balasubbareddy in [138] proposed another version called Hybrid AntLion Optimizer Algorithm (HALO) in which, they used the arithmetic crossover operation of Genetic Algorithm (GA). The results shown the superiority of HALO algorithm compared with BA, SMS, PSO, and original ALO.

In order to optimize the design of fuzzy controller Azizi *et al.* [142] hybridize ALO with Jaya algorithm. They applied their algorithm in seismically excited nonlinear buildings. Also, In [120] Yu proposed ALO-INM algorithm which is a hybridized algorithm between ALO and improved Nelder-Mead algorithm.

C. MULTI-OBJECTIVE ALO

In literature, there are many proposed versions of multi-objective ALO. Table 5 lists all multi-objective proposed versions. Mirjalili *et al.* in [143] proposed a multi-objective version of ALO called Multi-Objective ALO (MOALO). The proposed algorithm used a repository to store Pareto non-dominated optimal solution. A roulette wheel mechanism is used to select solution to guide ants.

Mirjalili *et al.* tested their algorithm via a various engineering problems namely: cantilever beam design, disk brake design, brushless dc wheel motor design, safety isolating transformer design, 4-bar truss design, speed reduced design, and welded beam design.

In [144], [145] Dos *et al.* proposed a 2 novel multi-objective version of modified ALO algorithm based on Tent Map and Lozi Map. They apply it to Transformer Design Optimization (TDO).

Also, in [146] another version of Multi-Objective ALO has proposed by Hosseini *et al.* They apply it to the optimal multi-objective scheduling of a Micro-grid.

Ahmed R. Abul'Wafa in [147] convert a multi-objective to a single one using weighted sum of individual objectives. He used it to simulate the optimal placement of Distributed Generators and Synchronous Condensers (DGs-SCs) based on ALO. Likewise, a novel version of multi-objective ALO called I-MOALO has been proposed [148] by Mahanta *et al.* They applied the novel version to obtain the optimal gripper. They compared the results with many multi-objective algorithms using well-recognised metrics such as: hyper volume, diversity, and non-dominated individual ratio.

V. APPLICATION(OPTIMIZATION & ENGINEERING)

ALO has been applied to many fields such as Engineering, Computer science, Mathematics, Medical and Energy. Figure 8 presents the distribution of these papers obtained from Scopus in different fields.

A. POWER

1) OPTIMAL POWER FLOW

The Optimal Power Flow (OPF) is a very important problem. OPF goal is to specify the parameter setting of fuel cost generation, gas emission, active transmission losses, etc. In [149] Salhi *et al.* applied ALO algorithm in Solving OPF problem. They tested it using IEEE 30-bus, and thier objective function are fuel cost, non-quadratic gas emission and total active losses.

Also, Trivedi *et al.* in [150] tried to solve OPF by reducing power loss and enhancing voltage stability using ALO. Their

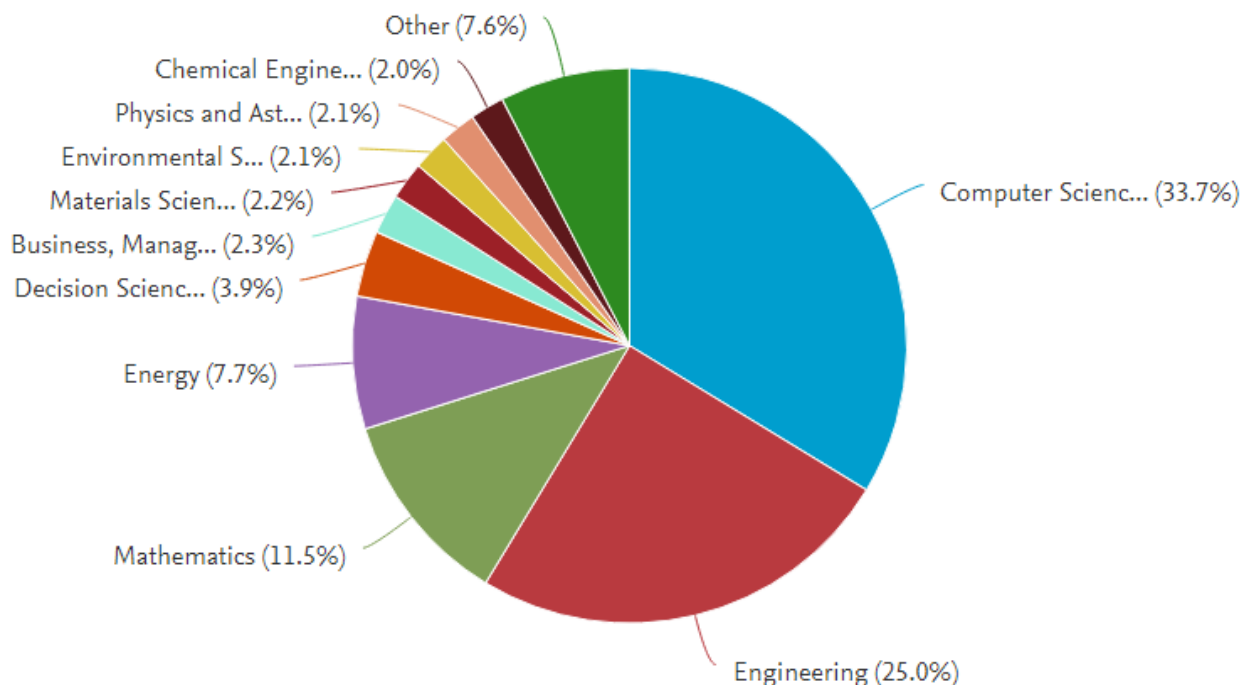


FIGURE 8. Distribution of ALO related papers in many application, as reported by Scopus.

considered objectives are reducing fuel cost, improving voltage profile, enhancing voltage stability, and reducing active and reactive power losses. They argued that ALO has better results than firefly algorithm (FA) and particle swarm optimization (PSO). In [151] a fuzzy decision making mechanism is incorporated in ALO to minimize the operating cost and maintain reserve and voltage level with respect to several operational concerns in current power system applications. Also, a hybrid ALO algorithm is proposed in [138] to solve optimal power flow problem.

2) LOAD DISPATCH

Economic Load Dispatch Problem (ELDP) refers to determining the least cost schedule of power generation to meet the system needs. Nischal and Mehta [152] tried to solve optimal load dispatch problem using ALO. They argued that their results is better than recent algorithm when tested using 3, 6 & 20 unit test. Also, Kamboj *et al.* [153] tried to solve dynamic and non-convex ELDP of electric power system. They used 4 IEEE benchmark and compared their resulted with lambda iteration method, PSO, GA, ABC, EP and GWO. In [154] REDDY and REDDY tried to solve ELDP using practical constrains such as ramp rate limits, prohibited operating zones, generation operating limits, transmission loss, valve-point loading and non-linear emission functions. Likewise, Rebecca *et al.* [155] proposed a version of ALO to solve optimal reactive power dispatch. Tung and Chakravorty in [156] tried to find the optimal scheduling of thermal units for small electrical Scale Economic Power Dispatch Problem. Also, in [157], [158] authors proposed an approach

to solve optimal reactive power dispatch (ORPD). Also, Alazemi and Hatata [159] Considered Demand Response as a Visual Power Plant to solve the Optimum Economic Dispatch problem.. Also, Hatata and Hafez [160] employed ALO, PSO, and AIS in solving ELDP problem by trying to minimize cost, emission levels, and system losses. In [159], another attamp to solve economic dispatch with respect to demand response as a visual power. Demand response can be defined as the reduction in electric utility power consumption. Their proposed technique is tested by using 2 systems 6-bus system and IEEE-30 bus system.

3) POWER DEVICES: ALLOCATING & CONTROL

Wind turbine and photovoltaic are considered as a Distributed Generation (DG) sources. In [161] Ali *et al.* applied ALO in finding the optimal size and allocation of renewable DG. They tested their algorithm by using 33 and 69 bus radial distribution system. They argued that their results improve voltage profiles and maximize the net sharing for many loading conditions. The same authors in [162] use ALO with Loss Sensitivity factors (LSFs) by formulating DG problem as an optimization problem.

Also, another enhancements have been proposed in [163], [164] trying to obtain the optimal siting of DGs using ALO. In order to design the optimal fractional order PID (FOPID) controller, Prahan *et al.* [165] used ALO to optimize FOPID parameters. Authors used many performance indices to prove the efficiency of their model such as Integral Absolute Error (IAE), Integral Squared Error (ISE), Integral Time Absolute Error (ITAE), and Integral Time Squared Error (ITSE).

B. COMPUTER SCIENCE

1) FEATURE SELECTION

Feature Selection (FS) is the process of selecting a significant subset of properties from a huge set [198], [199]. FS is used to enhance the performance of classifier and increase classification accuracy. Zawbaa *et al.* [166] applied ALO algorithm in FS problem. They compared their algorithm with Genetic Algorithm (GA) and Particle Swarm Optimization (PSO).

The authors in [135] applied a chaotic version of ALO in FS. Mafarja *et al.* in [167] used a 6 transfer functions based on (S-shaped and V-shaped). Also, Emary *et al.* applied their 3 variants of binary ALO in FS problem [110]. The same authors [129] applied Lévy ALO (LALO) to solve FS problem. They tested their algorithm using 21 benchmark dataset. Likewise, Wang *et al.* [130] applied their modified version of ALO to reduce dimensionality of hyperspectral image.

2) IMAGE PROCESSING & COMPUTER VISION

In Literature, there are many papers that successfully applied ALO in image processing applications. In [168] Mostafa *et al.* introduced ALO based model for MRI liver images segmentation. To test their model authors used a set of 70 images and validated the success of their algorithm by using Structural Similarity index (SSIM). Also, Parvathi and Rajeswari [139] integrated Fuzzy C Means (FCM) with ALO in an algorithm called FCM-ALO and applied it in image segmentation. Oliva *et al.* [169] tried to enhance the segmentation image quality by using ALO with Multilevel thresholding (MTH). Toz [117] introduced a new approach to improve clustering quality. They compared their algorithm with particle swarm optimization, artificial bee colony, genetic, and K-means algorithms.

To detect the change in natural environment, texture can be considered as a significant characteristics. Wang *et al.* [170] used ALO to achieve the satisfactory convolutional mask by considering it as a combinatorial optimization. Their results prove the ability of ALO in and classification accuracy which has reached 91% and fitness value with 27%.

3) NEURAL NETWORK

To determine the weights and biases of the Multi-layer Perceptrons (MLP), Yamany *et al.* [171] used ALO to train MLP trying to obtain the highest classification rate and the lowest error value. Heidari *et al.* in [172] introduced a hybrid technique called ALOMLP which is based on a hybrid training methods ALO and Multi-Layer-Perceptrons (MLPs). Authors compared the results with DE, GA, PSO, and PBIL. The results showed the superiority of ALOMLP in classifying almost datasets. Also, Dubey *et al.* [173] integrated ALO and Artificial Neural Network and applied it for Chaotic Electroencephalogram (EEG) Prediction. In [174] an optimized Fuzzy PID based on ALO algorithm is proposed which is supervised on Line Recurrent Fuzzy Neural Network Based Controller. In [175] recurrent neural network and ALO is

integrated by Roy *et al.* and applied to manage the micro grid connected system. Reference [176] Hassim and Ghazali tried to solve Functional Link Neural Network (FLNN) to solve classification problems. The classification results of FLNN-ALO is better than the standard FLNN. Likewise, Sekhar and Ravi in [177] proposed a hybrid controller which is a joined execution of the ant-lion optimizer with the recurrent neural network called the ant-lion recurrent neural network to improve the grid-connected wind energy low-voltage ride-through ability of the conversion system. Ansal [178] integrated ant lion optimizer with artificial neural network (ALO-ANN) to control dynamic voltage restorer (DVR). In [179] Kose employed Ant Lion Optimizer and Artificial Neural Network to perform some predications over electroencephalogram time series.

4) OPERATION MANAGEMENT

Fathy and Abdelaziz [180] used Krill Herd (KH) and ALO to manage both Single & Multi-Objective operation management. They formulated the problem as nonlinear constrained function. Their results were compared with GA, Fuzzy Self Adaptive PSO (FSAPSO), PSO, GWO, WOA.

C. WIRELESS NETWORK

These days, wireless sensor networks (WSNs) becomes more popular and common among human societies due to its enormous applications such as smart buildings, health-care, environment control, and surveillance. Yogarajan and Revathi [181] tried to improve cluster based routing by modeling cluster head selection as a fitness function and tried to improve the network performance by using ALO. They argued that their simulation results improved network lifetime, and reduced individual nodes number.

D. CIVIL ENGINEERING

Mishra *et al.* [182] used ALO to detect structural damage. They set the objective function based on vibration data. Several benchmark are used to prove the effectiveness of ALO. Also, Chena and Yu [183] applied their multi-objective ALO to detect damage in structural. They constructed objective function based on several parameters: mode shape and natural frequencies.

Also, In [184] Talatahari proposed a method to design skeletal structures using ALO.

E. MEDICAL APPLICATIONS

Kidney transplant operation is the only available choice for patient needs. In mathematics, kidney exchange can be considered as an optimization problem. Hamouda *et al.* [185] used ALO in Kidney exchange space by trying to maximize feasible cycles and chains numbers.

F. CHEMICAL ENGINEERING & QSAR

Elaziz *et al.* [186] used ALO to select the most relevant descriptors in Quantitative Structure-Activity Relationship (QSAR) in order to predict the potential chemical effects

on Environment and Health. ALO is used before constructing QSAR model to enhance the quality of ANFIS.

G. CONTROL ENGINEERING

PI and PID controllers are considered the most and popular linear controllers. This is because they have many salient features such as: good dynamic response, zero steady state error, and high disturbance rejection. In [187] Tummata *et al.* used ALO to tune PID controller of anti-windup.

Also, Saikia and Sinha [188] used ALO-based PID with second order derivative controller to generate an automatic controller of multi-area system. Likewise, Authors in [189] used ALO to evaluate the performance of automobile cruise control system. Also, Hatata and La [190] tested three algorithms namely: ALO, AIS, and PSO in order to find the Optimal Coordination of Directional Over Current relays (DOC) in Distribution Systems Containing DGs.

Also, Haroun and Li [191] combined ALO with Fractional order fuzzy PID controller to stabilize multi-area power system.

In [192], authors employed ALO to evaluate the performance of automatic generation control of interconnected power system. They used 2 fitness functions: Integral Time-Absolute Error (ITAE) and Integral Square Error (ISE). The results is carried out with GA, PSO, and GSA. Authors argued that ALO outperform metaheuristic algorithms. Fathy and Kassem [193] trained adaptive neuro fuzzy inference system (ANFIS) using ALO to control multi-interconnected plants comprise wind turbine and photovoltaic.

H. OTHER ENGINEERING APPLICATIONS

In [194] Nair *et al.* used ALO in order to identify an infinite impulse response(IIR) filters adaptively. They used 4 IIR benchmark with different orders and compared ALO with 2 metaheuristics algorithm GSA and CS.

Also, ALO has been successfully applied to distributed generation by Ali *et al.* in [162], [195]. They tried to find the optimal size and allocation of renewable distributed generation.

Algabalawy *et al.* [196] proposed a new version of ALO called Dynamic Adaptive ALO (DAALO) by using Levy flight instead of uniform distribution and applied it to route planning of unmanned aerial vehicle.

Abul'Wafa [147] used a multi-objective version of ALO in order to find the optimal allocation of distributed generations. He converted MOO formulation to a single objective from the weighted sum of the individual objectives.

In order to tune PID controller for automobile cruise control system, Pradhan *et al.* [197] used ALO. They designed PID as per Bode ideal transfer function. They argued that ALO based PID controller has better results than other metaheuristic algorithms.

VI. ASSESSMENT AND EVALUATION OF ALO

As mentioned above, ALO has been widely applied to a huge number of real-world optimization problems since its

appearance. This is because that the ALO has many advantages like simple inspiration, ease of implementation, and few number of controlling parameters. However, similar to other metaheuristic algorithms, ALO has many disadvantages. The main disadvantages of ALO is that it can't solve all optimization problem as stated by No Free Lunch (NFL) theorem. The second disadvantages is that in community detection problem, it's good and suitable only in small network size. However, ALO performance isn't good in large network size compare to other metaheuristic algorithms. Finally, the low ability to control all ALO parameter as they tend to converge to the same point.

VII. CONCLUSION AND POSSIBLE RESEARCH DIRECTIONS

In this paper, approximately 160 papers/articles were collected, summarized, and studied to show the advantages and disadvantages of ALO for computer science researchers & scientists who are interested in ALO as the first comprehensive review of the ALO. In this work, all variants of ALO, all applications in differentiated fields have been highlighted. However, some research trend that may be considered in future work are listed below:

- Dynamic & Dynamic Multi-Objective optimization: No work in literature has been proposed to dynamic problems. ALO & MOALO are very challenging since, in the dynamic environment, the optimal value changes over time.
- More research on the theoretical aspect of ALO is needed for more stable implementation.
- Parameter tuning is very important especially when ALO is applied to solve real-world application. Unfortunately, there is no work to handle a very large number of variables and ALO should be enhanced as ALO large scale is one of the main drawbacks

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