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BINARY AFRICAN VULTURES OPTIMIZATION ALGORITHM FOR Z-SHAPED TRANSFER FUNCTIONS

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ABSTRACT

Metaheuristic algorithms are of great importance in solving binary optimization problems. African Vulture Optimization algorithm (AVO) is a swarm intelligence-based heuristic algorithm created by imitating the life forms of African vultures. In this study, the AVO, which has been proposed in recent years, is restructured to solve binary optimization problems. Thus, Binary AVO (BAVO) has been proposed. Four different z-shaped transfer functions are chosen to convert the continuous search space to binary search space. Variations for BAVO are defined according to the transfer function used (BAVO1, BAVO2, BAVO3, and BAVO4). The success of these variations was tested in thirteen classic test functions containing unimodal and multimodal functions. Three different dimensions were determined in the study (5, 10, and 20). Each test function was run ten times independently and the average, standard deviation, best, and worst values were obtained. According to the results obtained, the most successful of these variations has been identified. According to the results, the BAVO4 variant at higher dimensions achieved better results. The success of BAVO with z-shaped transfer functions was demonstrated for the first time in this study.

Keywords: African vultures, Z-shaped transfer functions, BAVO

INTRODUCTION

In real-world problems, the search space does not always consist of continuous variables. Sometimes it can also consist of values that contain discrete values. Therefore, metaheuristic algorithms should be structured to solve not only continuous problems but also discrete problems. In discrete optimization, variables in the search space can consist of integers as well as binary values. Many different problems can be solved by using these binary values in the search space (feature selection, facility layout problem with no capacity, etc.). Such problems are called binary optimization problems. A heuristic algorithm that solves many binary optimization problems has been proposed in the literature. Al-Tashi et al. solved the feature selection problems with Hybrid Grey Wolf Optimization (Al-Tashi et al., 2019). They used 18 standard benchmark datasets and they preferred K-Nearest Neighbors (KNN) as the classifier. Baykasoğlu et al. proposed a weighted superposition attraction algorithm for binary optimization problems (Baykasoğlu et al., 2020). They selected three well-known binary optimization problems, including the uncapacitated facility location problem, 0–1 knapsack problem, and a natural extension of it, the set union knapsack problem. Baş proposed a Binary Aquila Optimizer for 0–1 knapsack problems (Baş, 2023).

In recent years, the newly proposed African Vulture Optimization (AVO) algorithm is a heuristic algorithm created by mathematically modeling the lifestyles of African vultures. In recent years, many studies have been done with AVO. Khodadadi et al. proposed a new multi-objective artificial vultures optimization algorithm (Khodadadi et al., 2022). Alanazi et al. proposed an optimal reconfiguration of a shaded PV-based system using the African vultures optimization approach (Alanazi et al., 2022). Xiao et al. proposed an improved hybrid Aquila Optimizer and African vultures optimization algorithm for global optimization problems (Xiao et al., 2022). Kumar and Mary proposed a study about parameter estimation of a three-diode solar photovoltaic model using an Improved-African Vultures optimization algorithm with the Newton–Raphson method (Kumar and Mary, 2021). Xi et al. proposed a Binary African vultures optimization algorithm for various optimization problems (Xi et al., 2022).

In this study, Binary AVO (BAVO) is proposed by converting the continuous search space of AVO to binary search space. During the translation into binary search space, four different z-shaped transfer functions are used (Guo et al., 2020). According to these transfer functions, four different BAVO variations were created. These are BAVO1, BAVO2, BAVO3, and BAVO4. The success of BAVO according to z-shaped transfer functions is shown for the first time in this paper. In this respect, the paper offers innovation. The success of the BAVO is demonstrated on 13 unimodal and multi-modal test functions.

AFRICAN VULTURES OPTIMIZATION ALGORITHM

Vultures fall into two main categories. These are the new world vultures and the old world vultures. New-world vultures are found in America, while old-world vultures live in Europe, Asia, and Africa. The body of most vultures is not completely covered with feathers. There are no feathers on the neck and head. They feed on animal leaves. They don't nest. The basic principles of AVO to model AVO mathematically: (Khodadadi et al., 2022)

There are at most N (population numbers) vultures in a search space.

- The total number of vultures is divided into two main groups. In AVO, the fitness solutions of the whole population are first calculated. The first two best solutions are chosen and the first two vultures are determined. The remaining population members form a population that moves or replaces one of the two best vultures at each performance (Khodadadi et al., 2022).
- In AVO, the worst vulture is the weakest and most hungry vulture. Other vultures try to stay away from him. The best and strongest vulture are the first two vultures. Population members try to best approach the first two vultures (Khodadadi et al., 2022).

AVO is mathematically modeled in four steps.

First scene:

After the initial population is established, the fitness of all solutions is calculated and the best solution is chosen as the best vulture of the first group and the second best solution as the best vulture of the second group. Other population members try to move best toward the first two vultures. In each cycle, the fitness values are reapplied for the entire population. The work of approximating the best first two solutions of the other groups is calculated by Equation 1 (Khodadadi et al., 2022).

$$R(i) = \begin{cases} Vulture_{Best1} & if\ P_i = L_1 \\ Vulture_{Best2} & if\ P_i = L_2 \end{cases} \quad (1)$$

$$Subject:\ L_1 + L_2 = 1$$

$$P_i = \frac{F_i}{\sum_{i=1}^{n} F_i} \quad (2)$$

The probability of choosing one of the two best solutions is obtained by Equation 2 (Khodadadi et al., 2022). $Vulture_{Best1}$ is the first best vulture of the group and $Vulture_{Best2}$ is the second-best vulture of the group.

Second scene:

Equations 3-4 were used to move from the exploration stage to the exploitation stage, inspired by the saturation or hunger rates of the vultures. Vultures often forage for food but fly longer distances if they are full. If a vulture is hungry, they don't have enough energy to fly for long periods and forage for food near the stronger vulture (Khodadadi et al., 2022). According to the $|F|$ value, it moves to the third scene or fourth scene. If $|F|$ value less than 1, AVO enters the exploration stage, otherwise, AVO enters the exploitation stage (Khodadadi et al., 2022).

$$t = h \times \left(sin^w\left(\frac{\pi}{2} \times \frac{iter_i}{Max\_iter}\right) + cos\left(\frac{\pi}{2} \times \frac{iter_i}{Max\_iter}\right) - 1\right) \quad (3)$$

$$F = (2 \times r_1 + 1) \times z \times \left(1 - \frac{iter_i}{Max_{iter}}\right) + 1 \quad (4)$$

F indicates that the vultures are satiated. $iter_i$ shows the current iteration number, Max_{iter} shows the maximum iteration number, z indicates a random number for range [-1, 1], h indicates a random number for range [-2, 2], and r_1 indicates a random number for range [0, 1] (Khodadadi et al., 2022).

<u>Third scene:</u> The Exploration

At this stage, the discovery phase of AVOA is modeled. In the natural environment, vultures have high visual acuity and the ability to find food and spot poor dying animals. But finding food for vultures can be very difficult. Vultures carefully study their environment for a long time and travel long distances in search of food.

In AVO, vultures explore the search space based on two different situations. Here, the selection process for both states is made according to P1. The discovery process in AVO is shown in Equations 5-8 (Khodadadi et al., 2022).

$$P(i+1) = \begin{cases} Eq.(6) \;\; if \;\; P_1 \geq \; Rand_{P1} \\ Eq.(8) \; if \;\; P_1 < \; Rand_{P1} \end{cases} \quad (5)$$

$$P(i+1) = R(i) - D(i) \times F \quad (6)$$

$$D(i) = |X \times R(i) - P(i)| \quad (7)$$

$$P(i+1) = R(i) - F + \; r_2 \times ((ub - lb) \times r_3 + lb) \quad (8)$$

F is the rate of the vulture being satiated and it is obtained using Equation 4. $R(i)$ is obtained using Equation 1. X is a coefficient vector ($X = rand \times 2$; $rand$ indicates a random number for range [0, 1]). $P(i)$ is the current vector position of the vulture. r_2 and r_3 indicate a random number for range [0, 1]. ub and lb indicate upper and lower bounds (Khodadadi et al., 2022).

Fourth scene: The exploitation

In this subsection, local search operations are continued according to P2 and P3 values.

Exploitation 1: Exploitation 1 enters for AVO when the |F| value is between 1 and 0.5. Competition for Food is shown in Equations 10 and 11. The rotating flight of vultures is shown in Equations 12 and 13 (Khodadadi et al., 2022).

$$P(i+1) = \begin{cases} Eq.(10) \;\; if \;\; P_2 \geq \; Rand_{P2} \\ Eq.(13) \; if \;\; P_2 < \; Rand_{P2} \end{cases} \quad (9)$$

$$P(i+1) = D(i) \times F + (r_4) - d(t) \quad (10)$$

$$d(t) = R(i) - P(i) \quad (11)$$

$$S_1 = R(i) \times \left(\frac{r_5 \times P(i)}{2\pi}\right) \times cos(P(i)) \quad (12)$$
$$S_2 = R(i) \times \left(\frac{r_6 \times P(i)}{2\pi}\right) \times sin(P(i))$$

$$P(i+1) = R(i) - (S_1 + S_2) \quad (13)$$

F is the rate of the vulture being satiated and it is obtained using Equation 4. $R(i)$ is obtained using Equation 1. $D(i)$ is obtained using Equation 7. $P(i)$ is the current vector position of the vulture. r_4, r_5, and r_6 indicate a random number for range [0, 1]. $d(t)$ represents the distance of the vulture to one of the best vultures of the two groups (Khodadadi et al., 2022).

Exploitation 2: Exploitation 2 enters for AVO when the |F| value is less than 0.5. Equations 15 and 16 have been used to formulate Exploitation 2 of vultures. The accumulation of several types of vultures over the food source is shown in Equations 15 and 16. Aggressive competition for food is shown in Equations 17 and 18 (Khodadadi et al., 2022).

$$P(i+1) = \begin{cases} Eq.(10) \ if \ P_3 \geq Rand_{P3} \\ Eq.(13) \ if \ P_3 < Rand_{P3} \end{cases} \quad (14)$$

$$A_1 = Vulture_{Best1}(i) - \frac{Vulture_{Best1}(i) \times P(i)}{Vulture_{Best1}(i) \times P(i)^2} \times F$$

$$A_2 = Vulture_{Best2}(i) - \frac{Vulture_{Best2}(i) \times P(i)}{Vulture_{Best2}(i) \times P(i)^2} \times F \quad (15)$$

$$P(i+1) = \frac{A_1 + A_2}{2} \quad (16)$$

$$P(i+1) = R(i) - |d(t)| \times F \times Levy(d) \quad (17)$$

$$LF(x) = 0.001 \times \frac{u \times \sigma}{|v|^{\frac{1}{\beta}}}, \sigma = \left(\frac{\Gamma(1+\beta) \times \sin(\frac{\pi\beta}{2})}{\Gamma(1+\beta 2) \times \beta \times 2(\frac{\beta-1}{2})}\right)^{\frac{1}{\beta}} \quad (18)$$

$Vulture_{Best1}$ is the best vulture of the first group and $Vulture_{Best2}$ is the best vulture of the second group. $P(i)$ is the current vector position of the vulture. F is the rate of the vulture being satiated and it is obtained using Equation 4. d represents the problem dimensions, u and v are random numbers between 0 and 1, and β is a fixed and default number of 1.5 (Khodadadi et al., 2022).

BINARY AFRICAN VULTURES OPTIMIZATION ALGORITHM

Four different z-shaped transfer functions are preferred in this study in converting the continuous search space to binary search space. A binary AVO (BAVO) variation was generated for each transfer function. These are named BAVO1, BAVO2, BAVO3, and BAVO4. The z-shaped transfer functions used in the study are shown in Table 1.

Table 1. Z-shaped transfer functions (Guo et al., 2020)

Variations of BAVO	Name	Expression
BAVO1	Z1	$z1(x) = \sqrt{1-2^x}$
BAVO2	Z2	$z1(x) = \sqrt{1-5^x}$
BAVO3	Z3	$z1(x) = \sqrt{1-8^x}$
BAVO4	Z4	$z1(x) = \sqrt{1-20^x}$

While the continuous search space of AVO was converted to binary search space, the size of each population individual was calculated as in Equation 19. In this study, thirteen classical test functions in three different dimensions (5, 10, 20) were tested. According to these dimensions, the size of each population individual was adjusted as 500, 1000, and 1500 for dimensions 5, 10, and 20, respectively (Equation 19). The parameter of the Z transfer function is set as 2, 5, 8, and 20 (Guo et al., 2020).

$$Dimension_{population\ individual} = Dimension_{Function} \times 50 \qquad (19)$$

EXPERIMENTAL RESULTS AND ANALYSIS

BAVO is coded on Matlab R2014a. The values of the parameter are shown in Table 1. These parameter settings were examined by Baş and BAVO was run with the values determined by her. Classic 13 unimodal and multimodal test functions were selected to test the success of BAVO. Each function was run in three different dimensions (5, 10, and 20). each function was run independently ten times. Four different comparison procedures were applied to the results obtained. These are mean (Ave), standard deviation (StdS), best, and worst values. AVO is translated into binary space with four different Z-shaped transfer functions. The variants of the BAVO were obtained for each transfer function. These are BAVO1, BAVO2, BAVO3, and BAVO4. The results obtained are shown in Tables 3-8. The best results are marked in bold.

When examining the best and average results for sizes 10 and 20, it was observed that BAVO4 was more successful than the other BAVO variants. Examining the average results according to dimension 5, BAVO3 achieved the best results. When examining the best results, BAVO1 and BAVO2 showed superior performance.

Table 2. The parameter values

Methods	Population size (N)	Maximum Iteration	Run	Dimension (D)	P1	P2	*P3*	*L1*	*L2*	*w*
BAVO	30	1000	10	5, 10, 20	0.6	0.4	0.4	0.9	0.6	2.5

Table 3. BAVO test results for D=5

F	BAVO1		BAVO2		BAVO3		BAVO4	
	Best	*Worst*	*Best*	*Worst*	*Best*	*Worst*	*Best*	*Worst*
F1	**0,00**	698,00	**0,00**	2,88	**0,00**	0,15	**0,00**	0,00
F2	**0,00**	3,26	**0,00**	0,27	**0,00**	0,03	**0,00**	0,02
F3	413,18	2916,69	22,52	3282,17	**11,83**	3311,46	720,76	2968,75
F4	**0,00**	15,32	**0,00**	3,12	0,10	7,84	**0,00**	3,38
F5	**3,47**	26938,72	4,06	13465,14	3,90	11570,78	3,95	54141,73
F6	5,58	660,96	**0,06**	54,87	0,37	33,52	1,01	611,37
F7	0,01	0,13	**0,00**	0,10	**0,00**	0,05	**0,00**	0,07
F8	-1922,32	-1011,52	-1749,09	-902,95	**-2040,13**	-902,95	-1674,25	-902,95
F9	**0,00**	18,47	0,10	19,69	**0,00**	12,08	**0,00**	13,83
F10	1,71	6,64	**0,00**	1,71	0,05	2,82	**0,00**	2,38
F11	**0,00**	1,64	0,05	0,65	0,05	0,51	0,07	0,58
F12	**0,13**	22,04	1,00	7,03	0,24	24,75	0,29	13,27
F13	0,48	254,81	**0,29**	1,26	0,39	1,04	0,50	1,65

Table 4. BAVO test results for D=5

F	BAVO1		BAVO2		BAVO3		BAVO4	
	Ave	*StdS*	*Ave*	*StdS*	*Ave*	*StdS*	*Ave*	*StdS*
F1	157,16	202,83	0,33	0,85	0,02	0,05	**0,00**	0,00
F2	1,53	1,19	0,08	0,08	0,01	0,01	**0,00**	0,01
F3	**1270,59**	862,69	1364,40	1063,37	1289,17	1133,30	1669,12	593,48
F4	7,47	4,68	1,13	0,88	2,26	2,59	**1,07**	1,17
F5	6159,57	8847,24	2562,02	4171,19	**2418,52**	3625,01	5822,95	16114,07
F6	117,91	189,67	11,34	16,33	**5,23**	9,73	84,01	179,94
F7	0,04	0,03	0,03	0,02	**0,02**	0,01	**0,02**	0,02
F8	**-1571,95**	245,49	-1419,35	277,12	-1222,09	359,08	-1242,43	215,43
F9	7,27	6,15	5,47	5,81	**4,43**	4,02	4,86	4,57
F10	4,19	1,93	**0,73**	0,73	1,40	1,02	0,97	1,12
F11	0,97	0,57	0,34	0,16	**0,30**	0,16	**0,30**	0,16
F12	8,38	7,68	**3,37**	2,12	6,75	6,79	4,07	3,57
F13	54,31	96,55	0,68	0,25	**0,66**	0,19	0,87	0,39

Table 5. BAVO test results for D=10

F	BAVO1		BAVO2		BAVO3		BAVO4	
	Best	*Worst*	*Best*	*Worst*	*Best*	*Worst*	*Best*	*Worst*
F1	604,77	5465,14	0,58	321,12	0,05	43,54	**0,01**	0,78
F2	5,11	15,46	0,64	2,87	0,03	1,44	**0,00**	0,40
F3	3995,19	14372,24	**2372,28**	10902,85	3176,54	11635,57	2546,28	12260,42
F4	24,22	54,31	10,74	28,45	**2,48**	23,37	3,02	25,86
F5	66070,77	2146342,49	300,79	42306,53	50,22	292406,33	**21,18**	117450,86
F6	1259,89	6251,35	**2,23**	686,95	5,20	2514,51	3,02	1377,91
F7	0,31	1,62	0,03	0,26	**0,02**	0,28	**0,02**	0,13
F8	-2460,90	-1805,89	**-3001,20**	-1805,89	-2997,02	-1805,89	-2964,10	-1805,89
F9	21,83	73,87	7,91	31,66	**1,24**	33,93	11,16	28,08
F10	7,08	17,86	1,44	8,35	1,53	4,08	**0,51**	5,09
F11	2,00	29,02	**0,14**	2,90	0,42	9,54	0,19	1,07
F12	24818,90	5695383,77	1,99	21,09	**1,42**	93,90	1,48	12,97
F13	316766,28	13608806,55	1,91	434,24	1,19	5,15	**1,01**	3,14

Table 6. BAVO test results for D=10

F	BAVO1		BAVO2		BAVO3		BAVO4	
	Ave	*StdS*	*Ave*	*StdS*	*Ave*	*StdS*	*Ave*	*StdS*
F1	2412,23	1570,16	55,13	94,02	7,97	12,17	**0,20**	0,22
F2	11,15	3,51	1,75	0,66	0,61	0,51	**0,05**	0,12
F3	10235,34	2871,42	6531,42	3174,41	**5824,50**	2368,42	6458,33	3124,10
F4	38,62	10,75	18,28	5,42	**13,75**	7,25	14,25	7,69
F5	887408,36	621862,67	**11268,60**	14158,60	61161,57	99480,21	26683,17	36090,12
F6	2866,24	1477,70	**229,89**	224,33	468,45	756,45	408,20	517,11
F7	0,92	0,34	0,12	0,06	0,11	0,08	**0,06**	0,04
F8	**-2043,73**	274,68	-1925,42	358,59	-2018,99	429,89	-1921,71	347,46
F9	48,08	18,06	16,92	6,63	**15,43**	8,70	17,77	5,19
F10	14,02	2,88	4,72	2,09	**2,35**	0,71	2,90	1,27
F11	16,47	8,58	1,27	0,83	1,63	2,65	**0,54**	0,31
F12	1248636,04	1651782,00	11,66	5,00	19,19	25,32	**6,10**	3,22
F13	5210318,13	4972351,95	46,15	129,37	2,66	1,08	**1,59**	0,59

Table 7. BAVO test results for D=20

F	BAVO1		BAVO2		BAVO3		BAVO4	
	Best	*Worst*	*Best*	*Worst*	*Best*	*Worst*	*Best*	*Worst*
F1	11797,29	24028,17	645,74	2752,72	151,07	2091,86	**45,82**	2749,59
F2	36,67	96,32	5,30	24,38	2,33	8,32	**0,40**	9,23
F3	24955,16	64526,99	21252,97	42574,31	18460,80	42716,79	**14227,50**	34433,87
F4	55,82	68,29	39,78	51,11	**25,52**	46,29	27,53	44,07
F5	10319310,99	76765001,56	41482,77	2081374,93	15900,42	7358618,94	**11191,71**	10436240,76
F6	6559,89	21293,05	1204,50	6679,43	174,13	5939,68	**62,61**	10181,40
F7	10,36	23,79	0,28	3,65	0,29	1,22	**0,21**	0,74
F8	-4258,02	-3611,78	-3611,78	-3611,78	**-3719,16**	-3611,78	-3611,78	-3611,78
F9	148,40	224,08	63,85	159,17	35,46	81,47	**31,24**	59,10
F10	15,75	19,94	9,71	19,94	5,30	13,56	**3,80**	12,08
F11	63,90	193,77	6,16	21,63	2,01	16,85	**1,27**	15,78
F12	6358102,64	91823215,14	10,79	165738,82	8,05	5901,36	**5,21**	28401,01
F13	62626129,81	207552420,20	2079,58	4385953,92	15,55	682972,60	**4,48**	12,36

Table 8. BAVO test results for D=20

F	BAVO1		BAVO2		BAVO3		BAVO4	
	Ave	*StdS*	*Ave*	*StdS*	*Ave*	*StdS*	*Ave*	*StdS*
F1	16464,80	3928,72	1347,21	697,94	603,78	596,03	**575,72**	794,99
F2	51,57	18,73	15,37	5,82	5,13	1,87	**3,66**	2,87
F3	45138,26	13059,88	31634,28	6709,76	28125,77	8034,91	**24185,97**	7298,53
F4	64,82	3,87	45,76	3,69	38,69	5,56	**34,87**	5,39
F5	39772034,89	18243594,45	864427,27	645499,28	1448154,04	2643848,57	**1767088,22**	3532710,46
F6	15143,47	4469,15	2675,30	1809,85	**1536,86**	1546,64	2955,95	2779,37
F7	14,77	4,08	1,72	1,07	0,79	0,34	**0,42**	0,15
F8	**-3676,41**	193,87	-3611,78	0,00	-3622,52	32,21	-3611,78	0,00
F9	190,69	22,63	97,36	26,37	62,02	11,57	**46,01**	9,39
F10	19,37	1,28	15,11	3,95	9,90	3,02	**7,91**	2,82
F11	153,65	38,12	13,45	4,26	6,49	4,26	**3,68**	4,12
F12	42510032,05	27377666,54	43218,66	53999,04	**1735,43**	2313,87	3619,43	8513,82
F13	135692513,79	51627993,33	962904,73	1353056,71	92209,82	202019,41	**8,08**	2,32

CONCLUSIONS

In this study, AVO, one of the recently proposed heuristic algorithms, has been examined. AVO was originally proposed as an algorithm for solving continuous optimization problems. In this study, AVO is restructured to solve binary optimization problems. Although there are many transfer functions in the literature that converts continuous search space to binary search space (S-shaped, V-shaped, etc.), newly proposed Z-shaped transfer functions have been selected in this study. Thus, binary versions of BAVO are structured according to Z-shaped transfer functions for the first time in this study. Four different BAVO variants (BAVO1, BAVO2, BAVO3, BAVO4) were tested on 13 classical unimodal and multimodal test functions with success in three different dimensions (5, 10, 20). The best, worst, mean, and standard deviation calculations were made on the results and the results were compared in a detailed way. According to the results, the BAVO4 variant at higher dimensions achieved better results.

In future studies, it is considered to test the success of the BAVO4 variant in different binary optimization problems.

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