Modified Adaptive Bats Sonar Algorithm with Doppler Effect Mechanism for Solving Single Objective Unconstrained Optimization Problems

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***Abstract*—A modified adaptive bats sonar algorithm with Doppler Effect (MABSA-DE) is a new algorithm with an element of Doppler Effect theory that helped the transmitted bats' beam towards a superior position. The performances of the proposed algorithm is validated on a several well-known single objective unconstrained benchmark test functions. The obtained results show that the algorithm can perform well to find optimum solution. The statistical results of MABSA-DE to solve all the test functions also has been compared with the results from the original MABSA on similar test functions. The comparative study has shown that MABSA-DE outperforms the original algorithm, and thus, it can be an efficient alternative method in solving single objective unconstrained optimization problems.**

Keywords—Bat Algorithm, Doppler Effect, Metaheuristic, Optimization Algorithm, Single Objective Optimization

I. INTRODUCTION

Optimization is the method of finding an optimum solution to obtain best values of parameters for the problems under stated situations by implementing the method in comparing some solutions till an ideal solution is found via an optimization algorithm [1]. This situation has led many researchers to use the optimization technique to solve engineering optimization problems.

Metaheuristic techniques are recognized global optimization method that effectively applied in real world for developing systems and solving complex optimization problems. Metaheuristic algorithms are the algorithms where it derives their inspiration based on nature world [2]. These techniques are tries to mimic natural phenomenon such as animal behavior or process biological evolution, so as to generate better solutions for optimization problems [3]. The most recognized of nature-inspired metaheuristic algorithm is biologically-inspired algorithms. The efficiency of bio-inspired algorithms is due to their significant ability to imitate the best features in nature [4]. Several bio-inspired algorithms generally divided into two main groups which are evolutionary algorithm and swarm intelligence algorithm.

A past two decade, a swarm intelligence algorithm is one of the promising method in artificial intelligence method to solving single objective optimization problems where it was inspired based on simulation of the collective behavior of a social group of a living species such as birds, insects, fish and others [5]. Lately, swarm intelligence has gained increasing attention among the researchers to solve optimization problems. Their characteristics such as co-evolution, self-organization and learning during iteration process makes swarm intelligence algorithm become more popular among metaheuristic algorithms. The examples of swarm intelligence are ant colony optimization (ACO), firefly algorithm (FA), cuckoo search (CS), bee algorithm, particle swarm optimization (PSO) and bat algorithm (BA).

This paper introduces a new swarm intelligence algorithm called modified adaptive bats sonar algorithm with Doppler Effect (MABSA-DE) which is an upgraded version of the original modified adaptive bats sonar algorithm (MABSA) by [6]. In MABSA, there is a random factor used in order to update the end position of solution. This algorithm is proposed to replace the random factor with an adoption of a wave theory called Doppler Effect. Therefore, Doppler Effect is the mechanism that was implemented in MABSA for solving single objective optimization problems.

This paper is divided into several sections. Section II, the original MABSA is briefly described. In Section III discussed about the Doppler Effect theory. Then, the new proposed algorithm which is modified adaptive bats sonar algorithm with Doppler Effect (MABSA-DE) is presented in Section IV. While, in Section V discusses computer simulation results and finally conclusions are drawn in Section VI

II. MODIFIED ADAPTIVE BATS SONAR ALGORITHM

MABSA was introduced by [6] in 2017 by redefining as well as reformulating some elements in adaptive bats sonar algorithm (ABSA) by [5] in 2016. The MABSA is formulated after adjusting three search actions of the original ABSA and adding a new mechanisms to it. The three procedures are the ways to setting up the *beam length* (L), determining *starting angle* (Θ_m) and *angle between beams* (Θ_i) and also calculating *end point position* (pos_i). On the other hand, the bounce back strategy is a new component that has been incorporated in the MABSA, which was not considered in ABSA previously.

This part will describe just of the way to calculate the *end point position* (pos_i). While the other components of MABSA will not further discussed here as they were presented in [6]. In the MABSA, the pos_i for each transmitted beam is designed as in equation (1):

$$pos_i = \alpha \times pos_{SP} + \beta \times L\ (cos[\Theta_m + (i-1)\Theta])^{\omega} \qquad (1)$$

where $i = 1, \ldots, NBeam$; $NBeam$ is number of beams and pos_{SP} is beam's starting position.

There are two random variables in Equation (1). The first random variable is called *position adaptability factor* (α). This factor has the same characteristic as random variable walk method where the value for α is randomly selected from the range between 0 and 1. This factor is included to ensure that each bat can adapt to the new pos_{SP} faster as obtained from the previous pos_{SP}, $\mathrm{pos}_{\mathrm{LB}}$, pos_{RB} and pos_{GB}.

While, the second random variable is *collision avoidance factor* (β). The factor is essential to prevent the beams from overlapping or accidentally colliding with other bat's beam as every bat has produced a number of beams from new pos_{SP} simultaneously. Values for β are also randomly selected from ranges between 0 and 1. Therefore, due to the random factors used in MABSA to update the end position of solution, a new mechanism was implemented in this algorithm called Doppler Effect.

III. DOPPLER EFFECT

The Doppler effect is the change in frequency or wavelength associated with observers moving relative to the wave source. Compared to the emitted frequency, the received frequency is higher during the approach, identically at the instant of passing by and lower during recession [7]. These phenomena can be illustrated mathematically as follows:

$$f = [\ (\ c \pm v_r\ )\ /\ (\ c \pm v_s\ )\ ] * f_o \tag{2}$$

where f and f_o is the receiving and emitted frequency respectively. While, v_r is the speed of the receiver, v_s is the speed of source and c is the speed of wave in the air which is 340m/s.

The Doppler Effect can be perceived for any of wave; water wave, sound wave, light wave and others. Then, the Doppler Effect based on sound wave is the most familiar among us because of our experiences with sound wave. For example, as the emergency vehicles were travelling near us on the highway with its siren blasting, the pitch of the siren sound was high and then suddenly after the car passed by the pitch of the siren sound was low. That was the Doppler Effect where an apparent shift in frequency for a sound wave produced by a moving source.

Nowadays, Doppler Effect has been applied to a varied range of optimization applications in various fields to solve various problems. For examples, Doppler Effect was implemented in acoustic wireless sensor networks for tracking higher-speed targets [8] and in ultrasonic broadband signals that implemented the DE with an indoor acoustic simulator [9]. The DE mechanism also has been used in the bat algorithm itself where the new algorithms are proposed which are modified bat algorithm with Doppler Effect (DEBA) and novel of bat algorithm (NBA) [10, 11]. All these variations have proved to be very efficient on their particular cases but as we know that the DE can enhance the performance of many applications.

IV. MABSA WITH DOPPLER EFFECT

MABSA with Doppler Effect is a new modified algorithm where an element of Doppler Effect theory is used to substitute the random theory of collision avoidance factor (β) in (1). By using the Doppler Effect theory, wave from the source which is emitted by a bat will be a guide for other bats to follow that source wave. Now, rather than it only can avoid the beams from overlapping or collide between bat's beam, this approach will make it act as a guidance mechanism to help the transmitted bats' beam towards a better position.

Based on Doppler Effect theory, the *collision avoidance factor,* β can be write as (4).

$$f = [(c - 0)\ /\ (c + 1.4c)] * f_o = 0.42 f_o \tag{3}$$

$$\beta = 0.42 f_o \tag{4}$$

where β denotes the frequency received by the other bats, the initial, $\beta \in [0,1]$ is a random number. f_o is the emitted frequency where 25kHz until 100kHz [12]. In this modification, it takes an analogy that sound source has now surpassed the speed of sound in the medium, and is travelling at *1.4c*. Since the source is moving faster than the sound waves it generates, it actually leads the advancing wave front. The sound source will pass by a stationary observer behind the source will receive a lesser frequency as in (4) and this is where the modification was inspired.

V. RESULTS AND DISCUSSION

In order to validate the performances of MABSA-DE, it was verified on single objective benchmark test functions, where five of unconstrained test functions were selected [13]. The selected unconstrained benchmark test functions come from a different categories; many local optima, bowl-shaped, plate-shaped, valley shaped, and others. The details about the selected benchmark test functions are presented in Table I. Then, for each test functions, 30 independent runs were carried out with random bats, around 700 to 1000 bats by 100 maximum iterations, and a fixed value of emitted frequency which is 25 kHz.

The performance characteristics that are giving an attention are the best optimum value, worst optimum value, mean and standard deviation over 30 runs of algorithm. All the results obtained are tabulated in a Table II. From the result obtained, the MABSA-DE approach can get the optimal global optimum values and certain of them close to it through 30 runs. The MABSA-DE also give a lower value of best optimum value when tested on UN1, UN2a, UN2b, UN4a and UN4b compared to the original MABSA. Moreover, if the algorithm achieved or smaller than the global optimum value of the functions, that algorithm is actually giving the best performances on it.

In addition, the standard deviation also can determine the performances of the algorithm because the smallest results of standard deviation is show that the best precision of the algorithm. A low standard deviation means that most of the results are very close to the average and more reliable. Whereas, a high standard deviation means that the results are spread out and less reliable. From the result obtained in Table II, the MABSA-DE also can achieved the low standard deviation for most of the benchmark test functions. As can see, the MABSA-DE has a low standard deviation, although it has the same best optimum value with the original MABSA for UN5 function.

Then, a comparison graph of the average percent deviation between MABSA and MABSA-DE on five test functions with different dimensions are presented in Figure II. From this graph, the standard deviation of MABSA and MABSA-DE are presented in percentage to show the difference between the algorithms for a better view. Besides, the ANOVA test is a way to find out if the results are significant. Table III shows a contrast of the performance between MABSA and MABSA-DE using one-way analysis of variance (ANOVA) on the mean value ± standard deviation of the global optimum value for unconstrained benchmark test functions. The table shows that results of MABSA-DE on unconstrained test functions are significant and important to show that this algorithm can achieve a superior global optimum value.

Overall it can be concluded that MABSA with Doppler Effect makes the algorithm find a better solution compared the original MABSA. Thus, as proof, it can outperforms the global optimum values of the unconstrained benchmark test function and also for the accuracy and precision to find the global optimum solutions either on maximizing and minimizing problems.

VI. CONCLUSION

A MABSA-DE is proposed for solving unconstrained single objective optimization problems. MABSA-DE has been formulated from the original MABSA developed by [6]. A new strategy has been added on *collision avoidance factor* (β), called Doppler Effect as a guidance mechanism to help the transmitted bat's beam towards a better position instead of only as avoiding collision mechanism.

The MABSA-DE has achieved competitive results on the unconstrained benchmark test functions at a relatively better optimum solution value. From the comparative study, MABSA-DE has shown its capability to handle various single objective optimization problems, and its outstanding performance is much better than the original MABSA. The future works will be focus on the performance of the algorithm with the different values of emitted frequency on single objective optimization problems.

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TABLE I. UNCONSTRAINED BENCHMARK TEST FUNCTIONS

Functions	Category of function	Dimension	Range	Global optimum
UN1 (Schaffer)	Many local optima	2	[-100,100]	0
UN2a (Sphere)	Bowl-shaped	2	[-5.12,5.12]	0
UN2b (Sphere)	Bowl-shaped	5	[-5.12,5.12]	0
UN3 (Booth)	Plate-shaped	2	[-10,10]	0
UN4a (Rosenbrock)	Valley-shaped	2	[-2.048,2.048]	0
UN4b (Rosenbrock)	Valley-shaped	5	[-2.048,2.048]	0
UN5 (Branin)	Others	2	[-5,10],[0,15]	0.3978

TABLE II. RESULT OF UNCONSTRAINED BENCHMARK TEST FUNCTIONS

Functions	Global Optimum	Algorithm	Best	Worst	Mean	Std.
UN1	0.0000	MABSA	7.9128E-10	7.1916E-8	1.2044E-8	1.3989E-8
		MABSA-DE	8.5504E-11	4.6921E-8	1.0121E-8	1.3923E-8
UN2a	0.0000	MABSA	7.7799E-8	1.3595E-5	3.5227E-6	3.4980E-6
		MABSA-DE	9.3536E-11	1.5859E-8	3.6644E-9	3.8187E-9
UN2b	0.0000	MABSA	3.7389E-4	2.8727E-2	7.5989E-3	7.2740E-3
		MABSA-DE	4.1211E-8	5.6930E-7	2.2371E-7	1.7127E-7
UN3	0.0000	MABSA	2.8984E-7	5.2634E-5	1.5433E-5	1.3205E-5
		MABSA-DE	1.3895E-7	2.8342E-6	9.7358E-7	7.0589E-7
UN4a	0.0000	MABSA	7.5985E-7	9.922E-5	1.8228E-5	2.0870E-5
		MABSA-DE	2.8019E-9	2.2913E-6	4.4496E-7	5.5148E-7
UN4b	0.0000	MABSA	1.2083E-2	1.1658E-1	4.5811E-2	2.5451E-2
		MABSA-DE	2.3265E-3	2.3431E-2	1.0247E-2	5.0924E-3
UN5	0.3978	MABSA	0.3978	0.4006	0.3980	0.0004
		MABSA-DE	0.3978	0.3978	0.3978	0.0000

TABLE III. PERFORMANCE COMPARISON USING ONE-WAY ANALYSIS OF VARIANCE (ANOVA) BETWEEN MABSA AND MABSA-DE FOR UNCONSTRAINED FUNCTIONS OVER 30 INDEPENDENT RUNS

Functions	MABSA	MABSA-DE	Significantly
UN1	1.2044E-8 ± 1.3989E-8	1.0121E-8 ± 1.3923E-8	Yes
UN2a	3.5227E-6 ± 3.4980E-6	3.6644E-9 ± 3.8187E-9	Yes
UN2b	7.5989E-3 ± 7.2740E-3	2.2371E-7 ± 1.7127E-7	Yes
UN3	1.5433E-5 ± 1.3205E-5	9.7358E-7 ± 7.0589E-7	Yes
UN4a	1.8228E-5 ± 2.0870E-5	4.4496E-7 ± 5.5148E-7	Yes
UN4b	4.5811E-2 ± 2.5451E-2	1.0247E-2 ± 5.09924E-3	Yes
UN5	0.3980 ± 0.0004	0.3978 ± 0.0000	Yes

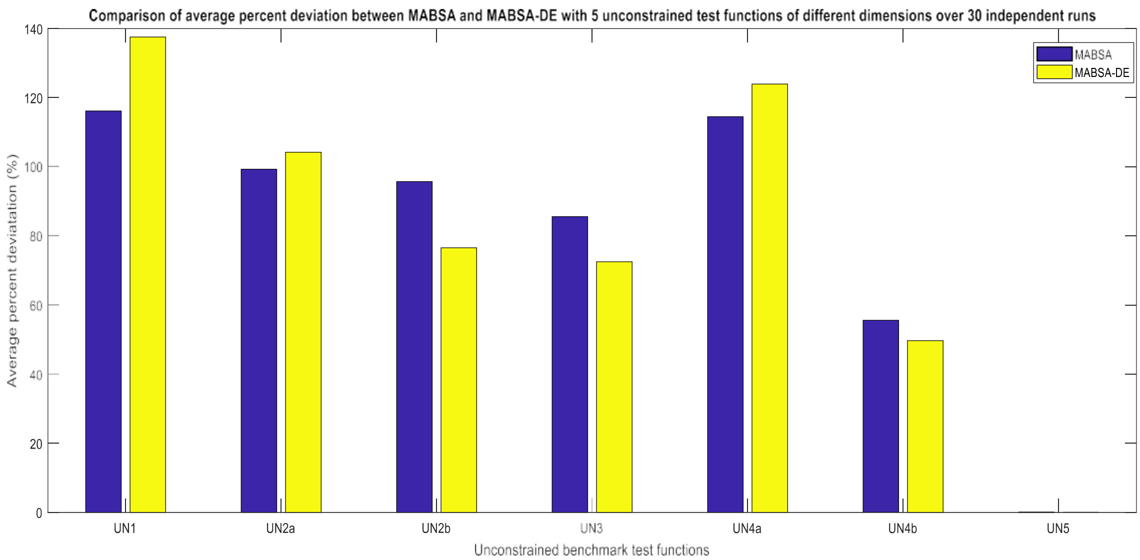

FIGURE II. COMPARISON OF AVERAGE PERCENT DEVIATION BETWEEN MABSA AND MABSA-DE WITH 5 UNCONSTRAINED TEST FUNCTIONS OF DIFFERENT DIMENSIONS OVER 30 INDEPENDENT RUNS