ICONTECH INTERNATIONAL JOURNAL OF SURVEYS, ENGINEERING, TECHNOLOGY
ISSN 2717-7270
Journal homepage: http://icontechjournal.com/index.php/iij
Volume 6 (2022) Issue 3

Vibrating Particles System Algorithm: Overview, Modifications and Applications

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Abstract

Real-world problems are difficult enough to encourages academics to develop innovative, effective problem-solving methods. Generally, metaheuristics algorithms that are inspired by nature, biology, and physics have a flexibility and capacity to adapt to different situations, metaheuristics based on evolutionary computation algorithms have been widely employed to solve complicated, constrained/unconstrained, single/multiple objective, and Non-deterministic polynomial hard (NP-Hard) optimization problems.

This paper describes Vibrating Particles System (VPS) as a Physics Based metaheuristic algorithm inspired by the free vibration of an under-damping objects for solving complex and real-world optimization problems. Since the appearance of VPS many modifications for improving the performance of the algorithm and has been applied to various Applications in several fields. At the end of this paper, the improvements are listed.

Keywords: Metaheuristics, Metaheuristics Classifications, Vibrating Particles System, VPS.

1. Introduction

A group of algorithms known as metaheuristics, which draw their inspiration from nature, are used to solve optimization issues in the most suitable way possible. Particularly when incomplete information is provided and there are limited computer resources, these approaches are recommended. In contrast to heuristics, metaheuristics may be used to solve problems using a few basic presumptions. When the solution space is too big to be entirely sampled, these techniques are used [1]. As seen in Fig. 1, there are various categories for metaheuristics algorithms.

Vibration is a mechanical phenomenon that causes oscillations around an equilibrium state. It is one of well-known Single-Objective Constrained Optimization Problems (SOCOP) in the engineering fields. Vibrations are classified into two types: (1) free vibration and (2) forced vibration [2]. This paper present Vibrating Particles System (VPS) algorithm, which is a Physics-Based algorithm belongs to Physics-inspired category of Metaheuristics algorithms, it is developed by Kaveh et al. in 2017 [3]. The VPS algorithm is inspired by the free vibration of an under-damping objects. This paper is an attempt to review the VPS algorithm and its proposed applications which help the researcher in future to apply it in other new and promising fields of application such as path planning and path following control of autonomous underwater vehicles.

2. Metaheuristics

A comprehensive search for the best solution to a particular problem is part of the optimization process. Numerous academic disciplines, including economics, computer science, engineering, and medicine, have difficulties that naturally requires optimization. Numerous researchers worldwide have focused on the creation of optimization algorithms [4]. The main objective of optimization algorithms, which are often referred to as search methods, is the construction of an ideal solution to an optimization problem such that the provided quantity is optimized subject

Received 11 July 2022; Received in revised form 12 August 2022; Accepted 8 September 2022;
Available online 25 September 2022;
doi: 10.46291/ICONTECHvol6iss3pp1-11

to a potential set of constraints. This definition of optimization may seem simple, but it actually hides a number of complex problems. some of the problems in the optimization process: (a) the solution may combine different types of data; (b) nonlinear constraints may limit the search space; (c) the convolution of the search space with numerous individual solutions; (d) the tendency of the problem's characteristics to change over time; and (e) the presence of competing objectives in the optimized quantity. These are a few of the issues that illustrate the potential complexity of an optimization technique [1].

Due to the exponential growth of the search space of problem, it is hard to find a viable solution using traditional optimization techniques when solving optimization problems with a high-dimensional search space. Consequently, it is not practical to address high-dimensional search space optimization problems using precise methods like exhaustive search. The failure of traditional optimization algorithms to identify enough global optima is another issue (local optima stagnation). Additionally, search space derivation is required for several of the traditional optimization procedures. Therefore, it is significant that these traditional techniques fail to address real-world optimization problems [5].

Metaheuristic algorithms are currently being used as the primary approach to achieving optimal solutions to real optimization issues. These techniques are distinguished from deterministic algorithms by the use of stochastic operators, which dependably determine the solution to a particular issue using identical starting points. Several engineering applications have demonstrated the value of metaheuristic algorithms in the optimization process. The fundamental issue with the optimization process. Generally, developing new methods for optimizing real world problem had an increasing attention, and as a result, many new metaheuristics algorithms were developed such as Artificial Bee Colony (ABC) [6], Cat Swarm Optimization (CSO) [7], teaching learning-based optimization (TLBO) [8], Colliding Bodies Optimization (CBO) [9] Ant Colony Optimization (ACO) [10], Particle Swarm Optimization (PSO) [11], Charged System Search (CSS) [12], Fish Swarm Algorithm (FSA) [13], Big Bang Big Crunch (BB-BC) [14], Krill Herd (KH) [15], Lion Algorithm (LA) [16], Dolphin Echolocation (DE) [17], Elephant Search Algorithm (ESA) [18], Grey Wolf Optimization (GWO) [19], Cuckoo Search (CS) [20], Vibrating Particles System (VPS) [21], and other optimization algorithms [22]. These algorithm are divided into various categories according to the algorithm inspiration source as shown in Fig(1) [1].

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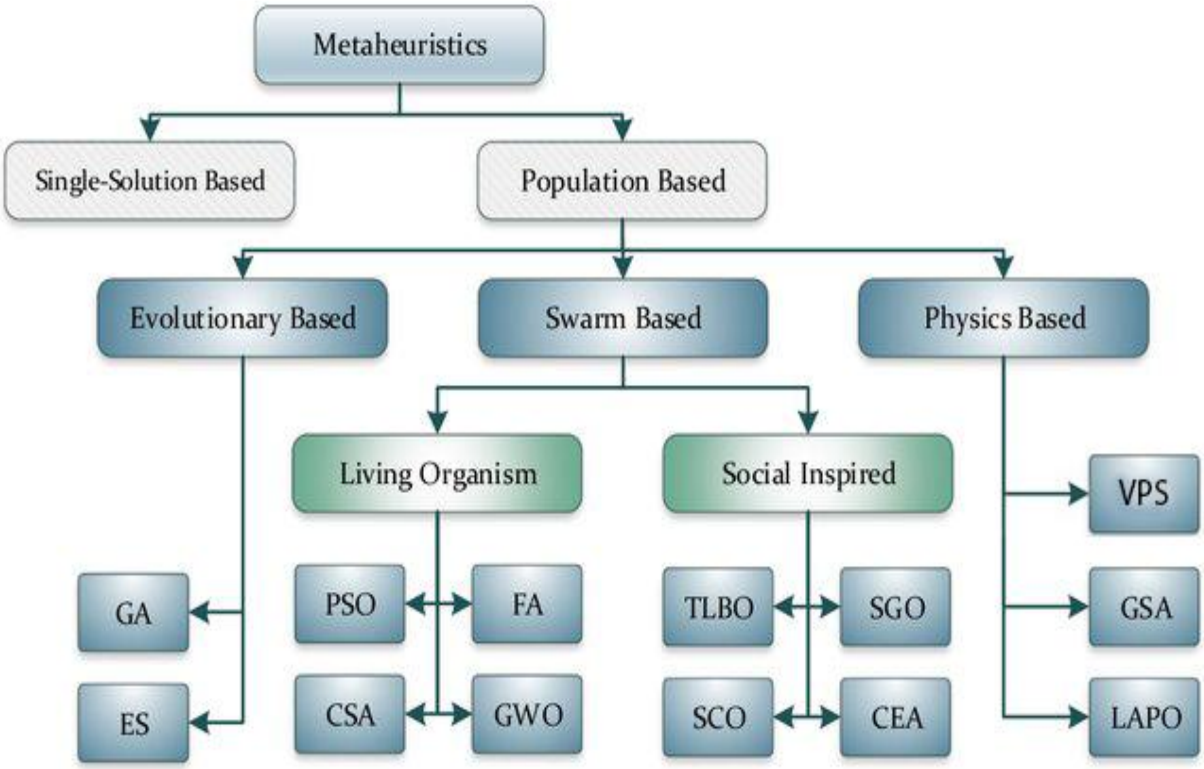

Figure 1: Metaheuristics algorithms classifications

3. Vibrating particles system (VPS)

The Vibrating Particles System (VPS) approach [18], developed by Kaveh and Ilchi Ghazaan in 2017, is an evolutionary metaheuristic search strategy that stimulates the free vibration of single degree of freedom systems with viscous dampening. VPS has been used to address a variety of structural optimization problems, with the results demonstrating its feasibility in terms of convergence and accuracy [21].

VPS, like other population-based metaheuristics, begins with a random collection of starting solutions and treats them as free vibrated single degree of freedom systems with vibration. When dampening conditions are applied to a free vibrating system, it oscillates and returns to its equilibrium point with a specified formulation. This is simply proven using differential equations. As the optimization process progresses, VPS enhances the particle quality on a regular basis by oscillating them forward towards the equilibrium position using a mix of randomization and exploitation of the data gained [19].

Consider that each particle's equilibrium position is made up of three positions: the best/highest position (HP), a good particle (GP), and a poor particle (BP). Thus, the essence of VPS is founded on three key concepts:

• self-adaptation: the particle moves toward HP.

• Collaborations: GP and BP, which are chosen from among the particles, can influence the new particle location.

• Competitions: GP's influence surpasses that of BP.

It should be noted that VPS uses a memory based on the harmony search approach to adjust the location of particles departing the search field [23].

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4. Vibrating Particles System

This section describes the VPS algorithm, its formulation, and the associated flowchart.

VPS Formulation

The formula employed to characterize the free vibration of an under-damped single degree of freedom (SDOF) system as follows in Eq(3).

$$X(t) = \rho e^{-\varepsilon \omega_n t} \sin(\omega_D t + \theta) \quad (3)$$

where ρ and θ are constants that are typically derived from the vibration's beginning circumstances, ω_n is the vibration's natural circular frequency. ω_D and ε are respectively, the damped natural frequency and the damping ratio that are shown in Fig 2 , and can be calculated by Eq(4) and Eq(5).

$$\omega_D = \omega_n \sqrt{1 - \varepsilon^2} \quad (4)$$

$$\varepsilon = \frac{c}{2m\omega_n} \quad (5)$$

All particles' initial positions in the search space are generated at random by Eq(6):

$$X_j^i = X_{min} + rand * (X_{max} - X_{min}) \quad (6)$$

Where X_{min} and X_{max} are the minimum and the maximum allowable variables vectors. And rand is a random number uniformly distributed in the range of [0, 1].

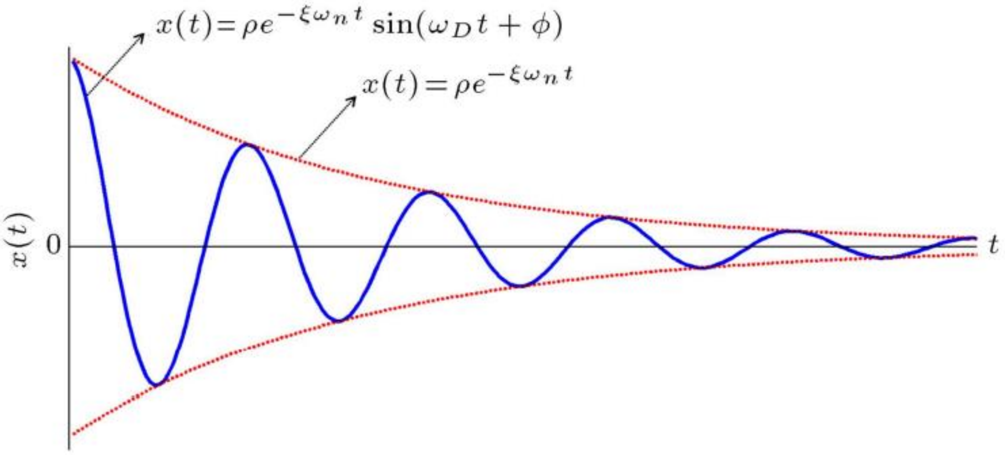

Figure 2. Vibrating motion of under-damped system.

As is evident, an under-damping SDOFs free vibrate and slowly comes into a its equilibrium point. And this vibrating characteristics is the idea which the VPS is inspires.

similar to other metaheuristics algorithms, VPS begins with a set of intrant solutions that are randomly produced inside the search space. nVP stands for the number of vibrated-particle. The

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appropriate objective-functions (Fit) and its penalized-functions ($PFit$) are generated once the items are evaluated [21].

VPS updates HP, GP, and BP with various weights (ω_1, ω_2,and ω_3) for each particle. After the population is sorted in ascending order by the values of the penalized objective function.For each particle, GP and BP are randomly selected from the first and second halves of the population, with the exception of itself.The damping level has a significant impact on vibration. The amplitude of a free damped vibration decreases as the damping level increases. To mimic this behavior in the VPS, the following descending function (D) relative to number of repetitions is calculated by Eq(7):

$$D = \left(\frac{NITs}{maxNITs}\right)^{\alpha} \tag{7}$$

$$maxNITs = \frac{\text{maxNFEs}}{nVP} \tag{8}$$

where NITs is the algorithm's current iteration number, maxNITs is the number of algorithm iterations selected as the halting criterion, maxNFEs is the number of function evaluations used as the stopping criterion, and is is a constant. Picking a value of 0.05 is advised [24].

The particles are updated by the equation Eq(9,10,11), often known as the free vibration formula, in accordance with the aforementioned ideas:

$$newVP_i = \omega_1(D * A * rand_1 + HP) + \omega_2(D * A * rand_2 + GP_i) + \omega_3(D * A * rand_3 + BP_i) \tag{9}$$

$$A = \omega_1(HP - VP_i) + \omega_2(GP_i - VP_i) + \omega_3(BP_i - VP_i) \tag{10}$$

$$\omega_1 + \omega_2 + \omega_3 = 1 \tag{11}$$

Considering the VPi as the current locations and newVPi as the updated locations of the ith particle's. The qualified significance of the ith particle's good particle, bad particle, and algorithm's best-yet particle are compared using different constant weights ω_1, ω_2, and ω_3 , and rand represents a random value uniformly generated in $[0 - 1]$ range.

In Eq(9 and 10), A and D effects on algorithm process similar to the effect of ρ and $e^{-\varepsilon\omega_n t}$ in Eq(3). The value of $\sin(\omega_D t + \theta)$ is measured as unity. A parameter p between $(0, 1)$ is initialized, and it specifies the influence of BP should/shouldn't considers when position are updating. p and random are compared as shown in Eq(12):

$$\text{If P<rand} \rightarrow \omega_3 = 0, \omega_2 = 1 - \omega_1 \tag{12}$$

Self-adaptation, collaboration, and competitiveness are three fundamental ideas that VPS takes into consideration [24].

- Self-adaptation happens as a particle moves in the direction of HP.
- Cooperation between particles is offered in VPS, where every particle has the capacity to influence the other's new location.

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• competition: The p parameter causes competition to arise because the effect of the GP (good particle) is larger than that of the BP (bad particle)

The VPS uses a harmony search-based handling method to deal with a particle that has gone outside the boundaries of the variables. The maximum vibrating particle's nVPs number, together with its related objective function (FitM) and penalized (PFit-M) values, are kept in a vibrating-particle memory in this research (VP-M). Vibrating particle memory was employed to store numbers as equal to nVP in order to accomplish this. Memory consideration and use in diverse approaches can increase metaheuristics efficiency without increasing processing costs. It should be noted that VPS utilized memory just to renew particles that had left the search region. This technique allows any member of the solution set that deviates from the bounds to be regenerated from the VP-M and is determined by Eq (13).

$$VP(i,j) = \begin{cases} w.p.\,vpmcr \Rightarrow & \text{select a new value for a variable from VP} - \text{M,} \\ & \text{w. p.}\,(1-\text{par})\text{do nothing,} \\ & \text{w. p. par choose a neighboring value.} \\ w.p.\,(1-vpmcr) \Rightarrow & \quad S\text{elect a new value randomly} \end{cases} \tag{13}$$

where "w.p." stands for "with the probability," and $VP(i,j)$ is the jth element of the ith vibrated particle, $vpmcr$ is the vibrating-particles memory with a rate within [0,1] and determines the possibility of selecting a value from the historic values saved in $VP-M$, and $(1-vpmcr)$ determines the probability randomly selecting a values in the possible range. After selecting a value from $VP-M$, the pitch-adjusting process begins. The value $(1-par)$ specifies the neglecting rate, and par specifies the rate of selecting a value from the particles bordering the best vibrating particle or those preserved in memory. Random generating step $size$ $(\pm bw * rand)$ can be used for continuous search space to choose a value from particles stored in memory or those closest to the best vibrating particle [20].

VPS flowchart

This section provide the flowchart of how the Vibrating Particles System (VPS) operate to solve different optimizations problems. It can be seen that the flowchart consists of three main steps:

• Initialization: in this step all the VPS attributes (maxNEFs, p, nVP, α, $vpmcr$, ω_1, ω_2, and ω_3) are initialized.

• Algorithm Body: in this step the optimization starts and the values of (D, HP, GP, BP, Fit, PFit, Fit_M, PFit_M, NFE, and maxNFE) are updated until the stop condition is satisfied.

• Results: after optimizing the result (PFit) this step define the way to display the optimal results.

Figure 4, shows the VPS flowchart.

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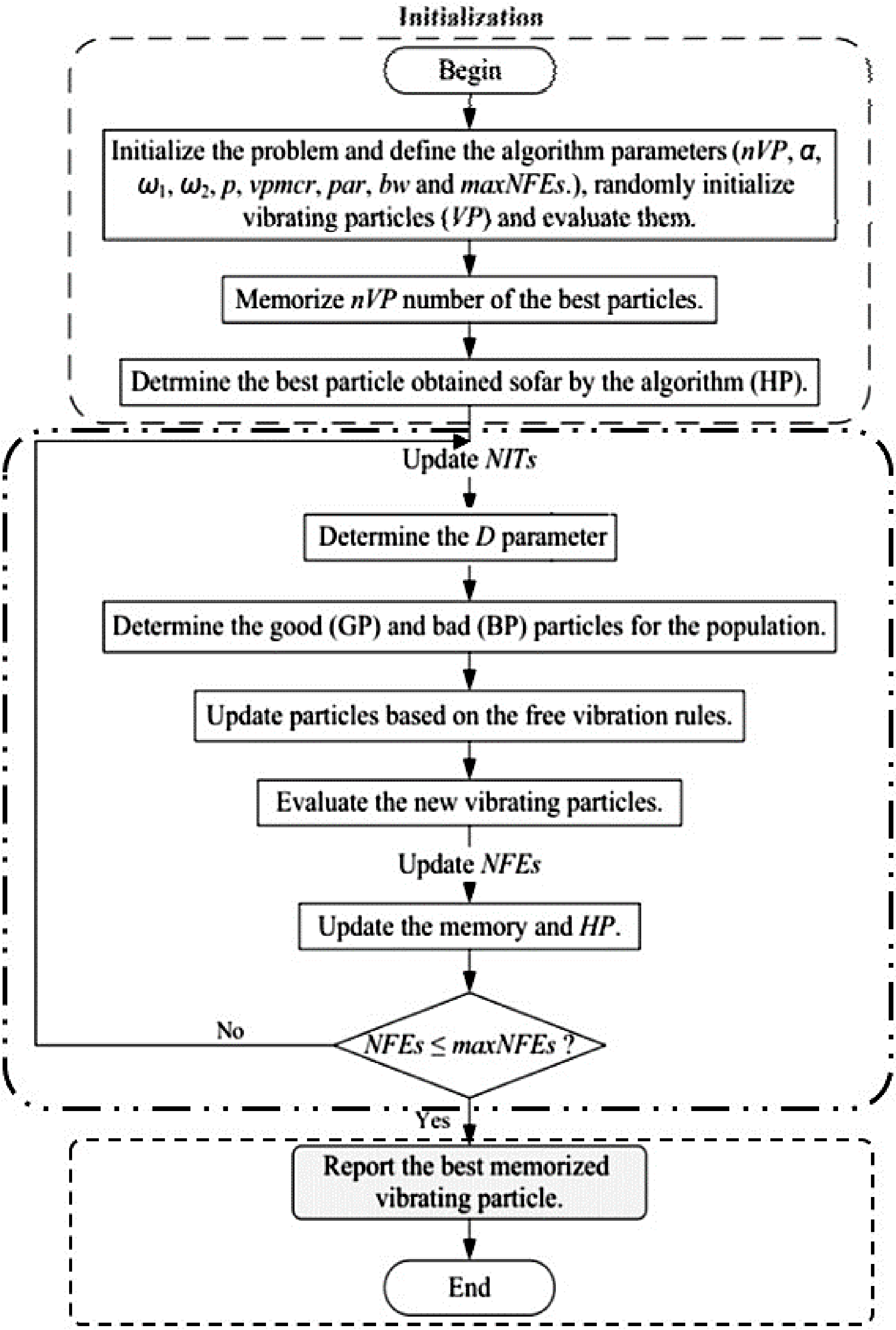

Figure 4: VPS flowchart

5. Modifications of VPS

In general, all metaheuristics algorithms undergo several adjustments and enhancements after their first appearance so that they may be utilized to tackle diverse issues.

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Following the release of the Vibrating Particles System (VPS) algorithm in 2017, various adjustments were made to the original VPS to increase the performance of the proposed algorithm.

Some of the adjustments and enhancements to the VPS algorithm are listed and organized in this part by development year, as show in Table (1).

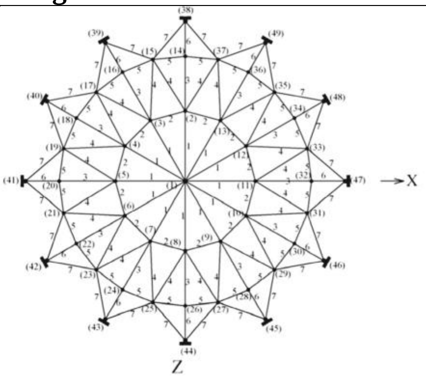
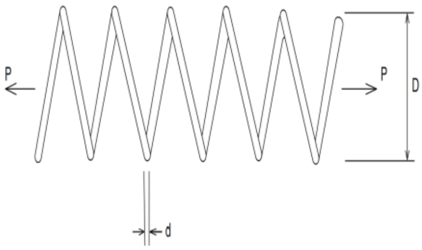
Table 1. VPS based algorithms

#	Abbr.	Name	Author	Year	Ref.
1.	VPS	Vibrating particles system	Kaveh et al.	2017	[3]
2.	EVPS	Enhanced Vibrating Particles System	Patrick et al.	2019	[25]
3.	MO-VBPSO	Multi-Objective Vibration-Based Particle-Swarm-Optimized	Liang Ou et al.	2020	[23]

6. VPS Applications

Over the years, the Vibrating Particles System (VPS) algorithm and its variations have demonstrated good performance in addressing several real-world issues, and it has been utilized to solve limited, single goal, and multi-objective problems in different areas, as shown in table 2.

Table 2. summarize VPS applications in different field

#	Application	Discussion	Image	Ref.
1.	optimum design of truss structures	In this method, the solution candidates are modeled as particles that progressively approach their equilibrium locations. Equilibrium locations are obtained by combining current population and historically optimal places in order to create a good balance between exploration and exploitation.		[24]
2.	tension/compression spring design problem	This approach is presented to converge a tension/compression spring design problem (TCSD) solution to an optimum solution. The mechanical phenomena of vibration creates oscillations around an equilibrium condition. It's one of the most well-known Single-Objective Constrained Optimization Problems (SOCOP) in engineering.		[21]

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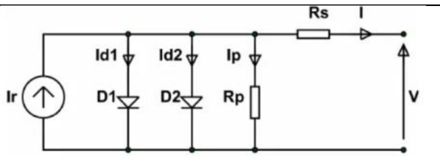
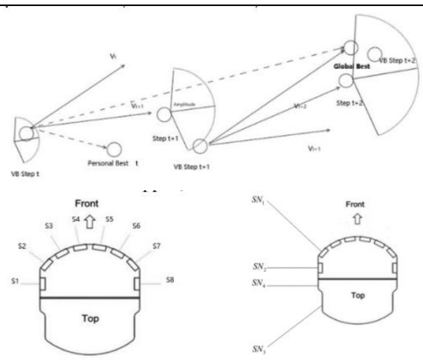
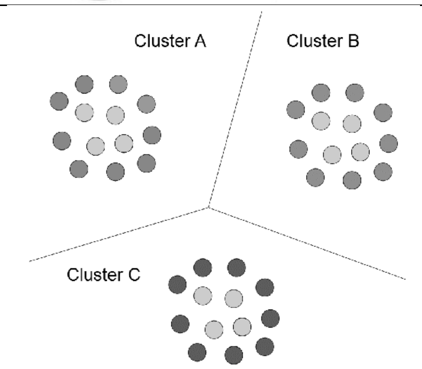
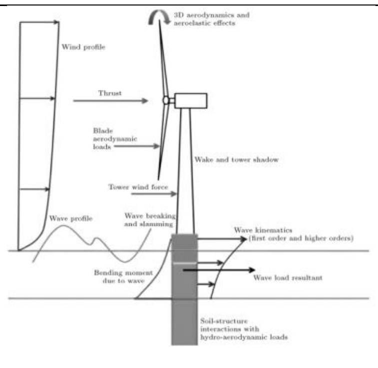
3.	Parameters Estimation of PhotovoltaicSystem	Several characteristics must be retrieved from the solar panel in order to evaluate its performance. These characteristics are critical for evaluating, monitoring, and optimizing solar systems. Enhanced vibrating particles system is one of the approaches created to extract photovoltaic characteristics from current-voltage (I-V) characteristic curves. It is inspired by free vibration of single degree of freedom systems with viscous damping.		[25]
4.	Boundary-Following of Mobile-Robot Simulation Environment	This paper presents a multi-objective vibration-based particle-swarm-optimization (MO-VBPSO) algorithm with enhanced exploration ability and convergence performance, for training fuzzy-controller (FC) to achieve robot control.		[23]
5.	Hard Clustering Problems	In the field of data analysis, clustering is an unsupervised technique that can be used to find identical sets of data. But, it is tough task to find the optimal centroid for a given dataset, especially in hard clustering problems. Recently, a vibrating particle system (VPS) algorithm was developed for solving the optimization problems.		[26]
6.	monopile offshore wind turbine structures	Considering both size and dimensions of the o shore wind turbine structures, design optimization of such structures is a fruitful yet, simultaneously, onerous task due to the tempestuous complexity of the problem, which mostly comes from their environment		[27]

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7. Conclusion

Vibrating Particles System (VPS) algorithm is a Physics-based metaheuristic algorithm proposed in 2017 by Kaveh et al. [21]. After its appearance, many modifications has been proposed on it and it has been adapt to solve various problem in different fields. This paper firstly addressed this overviewed the original VPS algorithm and then it presented some of its modifications were presented, finally some of its application considering were discussed. The applications in different fields including engineering optimization etc.

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