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METAHEURISTIC TECHNIQUES: REVIEW, ANALYSIS AND SCOPE OF APPLICATIONS

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ABSTRACT

Meta-heuristics algorithms have been demonstrated by the science community to be a feasible, and often superior, alternative to more classical methods of mixed-integer optimization such as branch and bound and dynamic programming. Meta-heuristic algorithm is widely used to tackling of optimization problems. Most of the multi-objective meta-heuristics belong to the class of evolutionary algorithms. This paper presents the state-of-art six recent algorithms, namely; Genetic Algorithm (GA), Ant Colony Optimization (ACO) Algorithm, Particle Swarm Optimization Algorithm (PSO), Firefly Optimization Algorithm (FF), Bat Algorithm, and Cuckoo search algorithm. In this study, we analyze the essence of these algorithms and their connections to self-organization. We also reviewed the applications of the proposed algorithms in this paper and summarized the scope of these applications. As a result, these mentioned algorithms in lead to some problems that have to be addressed in the future.

KEYWORDS: Robot path planning, Multi-objective Optimization, Genetic Algorithm, ACO, PSO, FA, BAT, Cuckoo Search**.**

1. INTRODUCTION

Nowadays, the development of an intelligent algorithm and their contribution to the development of Artificial intelligence is very rapid. In day-to-day activities, these techniques were needed. Different researchers used the concept of optimization in different applications, including engineering applications, transportation planning, management applications, economics, computational intelligence, Robotics, decision science, agriculture, tourism, sport science and, even political science etc.

Almost every day we see a new meta-heuristic algorithm. Nature has been an inspiration for the introduction of many meta-heuristic algorithms. In meta-heuristic algorithms, the process of searching can be carried out using multiple agents, which forms a system of evolving solutions using a set of rules during multiple mathematical iterations. The iterations are performed until some predefined criterion is not found. This Final solution is said to be the optimal solution.

Meta-heuristic algorithms are approximate solution methods for an optimization problem which use randomness, from a randomly generated set of feasible solutions, by exploring and exploiting the solution space. In a broad sense, optimization solution methods can be classified as exact and approximate solution methods.

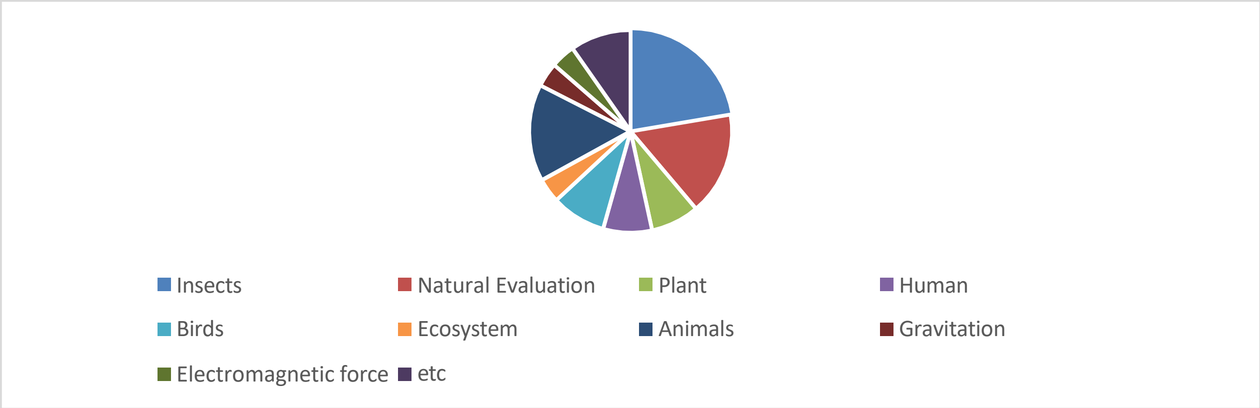

Figure 1: Meta-heuristic technique applications

In this Paper, six bio-inspired algorithms namely, Genetic algorithm, PSO (Particle Swarm Optimization), FA (Firefly algorithm), ACO (Ant-Colony Optimization), Cuckoo Search, and BAT algorithm were presented and analyzed for robot path planning optimization. According to current literature, some popular nature-inspired algorithms are as follows:-

1. Genetic algorithm, inspired by the Darwinian theory of survival of the fittest
2. Particle swarm optimization, based on the flocking behavior of the birds
3. Firefly algorithm, inspired by the flashing behavior of firefly
4. Ant-colony optimization, based on ant foraging behavior
5. Cuckoo search, based on the brooding behavior of cuckoo species
6. BAT Algorithm, is based on echolocation behaviour of micro bats

However, this is the short list of the algorithms; because there are more than 100 algorithms are available. Therefore it is not possible to cover all the algorithms in one paper. In this Paper, some meta-heuristic based optimization algorithms were discussed.

2. META-HEURISTICS OPTIMIZATION ALGORITHMS

2.1 Genetic Algorithm

Genetic algorithm was introduced by John Holland in 1960s. It works on Darwinian Theory of the survival of the fittest. Genetic algorithm uses coding method in the given search space. Each code provides a solution to the problem. The three main operations of genetic algorithms are Selection, Crossover and Mutation. The optimal path found by robot between two points is based on iteration between populations until collision avoidance is satisfied. The major focus on path planning should ensure minimum path length, path safety and path smoothness. Using genetic algorithm these parameters can be optimized. The basic components common to almost all genetic algorithms are:

- A fitness function for optimization
- A population of chromosomes
- Selection of which chromosomes will reproduce
- Crossover to produce next generation of chromosomes
- Random mutation of chromosomes in new generation

Pseudo code of Genetic Algorithm

```
BEGIN

Generate the 2D grid map

Initialize the start and goal point and obstacle position
Generate randomly initial population

WHILE NOT (converge condition met) DO
        Evaluate the fitness function of each chromosome
        Rank the population using fitness value (lowest fitness has higher rank)
        Apply crossover between two parents, while without changing the start and
        goal Apply the mutation operator

END
```

2.2 Particle-Swarm Optimization Algorithm

PSO was proposed by Kennedy and Eberhart in 1995. This algorithm is inspired by swarm behaviour such as bird flocking and schooling. In standard PSO, the new location of each particle is determined by a velocity term, which reflects the attraction of the global best and its own best. The reason of using the individual best is probably increasing the diversity in the quality solutions. The PSO is executed iteratively and the global best solution is calculated. The global best is selected in each iteration and the overall path is generated using overall global bests.

$$V_i{}^{t+1} = V_i{}^t + \alpha\varepsilon_1[g^* - x_i{}^t] + \beta\varepsilon_2[x_i{}^{*(t)} - x_i{}^t]$$

The new position is updated by,

$$x_i^{t+1} = x_i^t + v_i^{t+1}$$

Pseudo code of PSO Algorithm

```
Initialize particle, generate random path define as best path
For i in iteration do

    Definite particle velocity according to max and min allowed
    Limit path with the velocity using equation 1
    Update path with the velocity
    Limit path with environment
    size

    Define the best path according to lowest cost
End For
```

2.3 Firefly Algorithm

By observing the real firefly behavior, Xin-she Yang proposed the new intelligent algorithm named Firefly Algorithm. The main idea of firefly algorithm is to regard position of the firefly for a solution which determines by the brightness of the fireflies and their attraction towards others. The less brightness firefly moves toward the brighter one. The brightness of the firefly is inversely proportional to attractiveness and distance.

1. All fireflies are unisex and are attracted to each other regardless of their sex.
2. The degree of attractiveness of a firefly is proportional to its brightness and thus for any two flashing fireflies, the one that is less bright will move towards the brighter one. The distance between two fireflies will be less if the

brightness is more, The random movement equals the brightness of the flashing fireflies.
3. The objective function is generated for evaluating the brightness of fireflies.

$$\beta(r) = \beta_0 e^{-\gamma r^2}$$
$$x_i^{t+1} = x_i^t + \beta_0 e^{-\gamma r_{ij}^2}\left(x_j^t - x_i^t\right) + \alpha\varepsilon_i^t$$

Pseudo code of FF Algorithm

Begin

Objective function f(x), $x = (x_1, \ldots\ldots x_d)^T$
Generate initial population of fireflies x_i , i= 1,2, …., n
Formulate light intensity I so that it is associated with f(x)
While (t < MaxGeneration)
Define absorption coefficient γ for i=1 1:n (n fireflies)
for j=1:n (n fireflies)

if ($I_j > I_i$),
move firefly i towards j
end for

end for j
end if

Vary attractiveness with distance r via exp(-γr²) Evaluate new solutions and update light intensity

Rank the fireflies and find the current best
end while
Post-processing the results and visualization end

2.4 Ant-Colony Optimization Algorithm

ACO was developed by Dorigo and his associates in the early 1990s (Colorni et al., 1991, Dorigo, 1992, Dorigo et al., 1996). Ant-colony Optimization is derived from the behavior of the ant in the process of finding food. Each ant generates the special sustances called pheromones which help the ants to communicate with each other. In each iteration, the pheromone value is updated by al n ants that built a solution in the iteration itself. The higher concentration of the pheromone will be the best path and more ants attracts to it.

$$\tau_{ij}(t) = (1-\rho)\tau_{ij}(t-1) + \rho x_0$$

Pseudo code of ACO Algorithm

Initialize

While stopping criterion not satisfied do
Position each ant in a starting node
Repeat
For each ant do

Choose next node by applying the state transition rule.
Apply step by step pheromone update
End For

Until every ant has built a
solution Apply offline
pheromone update
End While

2.5 Cuckoo Search

CS algorithm is developed by Xin-She Yang and Suash Deb in 2009. CS is inspired by the behavior of the cuckoo birds breed. In the real cuckoo-host species, the eggs laid by cuckoos are similar to the eggs of the host species in term of size, color and texture. CS can be simplified using the following three ideal rules:-
Each cuckoo lays one egg at a time and dumps it

- Each cuckoo lays one egg at a time and dumps it in a randomly chosen nest.
- The best nests with high-quality of eggs will carry to the next generations.
- The number of available host nest is fixed and if a host bird identifies the cuckoo egg with the probability of Pa= 0.1, then the host bird can either throw them away or abandon them and build a new nest.

1. Each cuckoo lays one egg at a time and dumps it
2. ne

$$x_i^{t+1} = x_i^t + \alpha s \otimes \mathrm{H}(P_a - \varepsilon) \otimes [x_j^t - x_k^t]$$

Compared with other algorithms, Levy flights are used as a search mechanism, that host birds may abandon their nests and fly away if they suspect their eggs were replaced or contaminated.

$$x_i^{t+1} = x_i^t + \alpha L(s, \boldsymbol{\lambda})$$

Levy flights are random walks with steps:

$$\mathrm{L}(s, \lambda) \sim \frac{\lambda \Gamma(\lambda) \sin\frac{\pi \lambda}{2}}{\pi} \frac{1}{s^{1+\lambda}}$$

Pseudo code of CS Algorithm

Begin

Objective function f(x), $x = (x_1, x_2, \ldots, x_d)^T$;
Generate initial population of n host nests x_i , i = 1,2,…n
While (t< Max Generation) or (stop criterion)
Get a cuckoo randomly by Levy Flights
Evaluate its fitness F_i
Choose a nest among n (say j)
randomly If ($F_i > F_j$)
Replace j by the new
solution; End If
A fraction (p_a) of worse nests is abandoned and new ones are built;
Keep the best solutions (or nest with quality solutions)
Rank the solution and find the solution and find the current best
End while
Post process results and visualization
End Begin

2.4 BAT Algorithm

BAT algorithm was developed in 2010 by Xin-She Yang. BA are based on echolocation behaviour of microbats. Echolocation mechanism is a kind of sonar: bats, mainly micro-bats, create a loud and short pulse of sound and figure out the distance of an object by using the echo reruns back to their ears. BA uses frequency tuning and each bat is encoded with the velocity v_i^t and a locationx_i^t, at iteration t. The mathematical equation for updating the locations

x_i^t and velocities v_i^t can be written as

$$v_i^{t+1} = v_i^t + f_i[x_i^t - x_*]$$

$$\text{Where } f_i = f_{min} + (f_{max} - f_{min})\beta$$

$$x_i^{t+1} = x_i^t + v_i^{t+1}$$

After the position updating of bats, a random number is generated, if the random number is larger than the pulse emission rate, a new position will be generated around the current best solutions, and it can be represented by equation,

$$x_{new} = x_{old} + \varepsilon A^t$$

Pseudo code of BAT Algorithm

Define the objective function f(x),

Initialize the bat population $x = x_1, x_2, ..., x_n$,
for each bat x_i in the population do Initialize the pulse rate r_i, velocity v_i and loudness A_i,
Define the pulse frequency fi at x_i,
end
repeat
for each bat xi in the population do Generate new solutions through Equations 1, 2 and 3,
if rand>r_i then,
Select one solution among the best ones,
Generate a local solution around the best one,
end
if rand<A_i and $f(x_i)<f(x)$ then
Accept the new solution, Increase r_i and reduce A_i,
end
end
until termination criterion not reached,

Rank the bats and return the current best bat of the population,
Equations for Generating new solution

3. DOMAIN OF APPLICATIONS

Genetic algorithms are one of the most fundamental algorithms in computer science. Consequently, they have found many applications in the real world in different industries and for different tasks. Genetic algorithms are used to provide insight into the decisions a robot has to make. PSO has been successfully used across a wide range of applications, for instance, telecommunications, system control, data mining, power systems, design, combinatorial optimization, signal processing, network training, and many other areas. Nowadays, PSO algorithms have also been developed to solve constrained problems, multi- objective optimization problems, problems with dynamically changing landscapes, and to find multiple solutions, while the original PSO algorithm was used mainly to solve unconstrained, single-objective optimization problems.

Orng et al. demonstrated that firefly-based algorithm used the least computation time for digital image compression. In the engineering design problems, Gandomi et al. and Azad and Azad confirmed that firefly algorithm can efficiently solve highly nonlinear, multimodal design problems. FA can also solve scheduling and traveling salesman problem in a promising way.

Scheduling problems have been an important application area of ACO algorithms, and the currently available ACO applications in scheduling deal with many different job and machine characteristics. ACO algorithms have also been proposed for the permutation flow-shop problem (FSP). Notable examples are the work of Parpinelli et al.

and Martens et al. on applying ACO to the problem of learning classification rules. This work was later extended by Otero et al. . Cuckoo search algorithm is used in every domain like scheduling planning, forecasting, image processing, feature selection and engineering optimization. Hybrid CS was proposed by Li and Yin for shop scheduling problems. E.Valian et.al proposed Improved CS for Global optimization to enhance the accuracy and convergence rate . BAT algorithm and its modifications have been applied in almost every area of optimization, classifications, image- processing, feature selection, scheduling, data mining and others .

4. CONCLUSION

In conclusion, Meta-heuristic algorithms are presented and analyzed like GA, PSO, FA, CUCKOO, BAT, Ant - colony algorithms etc., based on the behavior of these species. These meta-heuristic techniques solved many continuous and discrete optimization problems. The simulation stage of these algorithms involves:-

1. First observe the behavior of the animals.
2. Design a model that represents a model of these animals.
3. Develop the pseudo-code for this proposed model.
4. Test the proposed algorithm theoretically and practically and analyzed the results of these algorithm.

Currently, the meta-heuristic optimization algorithm could hybridize, due to the problem of convergence speed. These meta-heuristics are hybridized with other approaches to enhance performance.

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