Interstella Search Method with Mesh Adaptive Direct Search for Optimal Design of Brushless DC Motor

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In this paper, a novel global search algorithm 'Interstella Search Method' (ISM) and its hybridization with Mesh Adaptive Direct Search (MADS) are proposed. ISM is population-based algorithm and is suitable for multimodal function, because of its capability to find diverse target islands of local optima in a short time. The hybridization with MADS support the fast convergence to local optima from target islands that are discovered in global search using ISM. The effectiveness of ISM was verified through the test function and compared with Genetic Algorithm and Particle Swarm Optimization. Lastly, ISM was applied to optimal design of Brushless DC motor based on Finite Element Analysis.

***Index Terms* — Brushless motors, Finite element analysis, Optimization**

I. Introduction

OPTIMAL design of electric machines based on Finite Element Analysis (FEA) requires an excessive computation time and has many local optima because objective function is sensitively changed by various design variables. Thus, optimization algorithms such as Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) have been used to minimize computation time by reducing the number of function call and reach global optimum without being trapped at local optima. In addition, the performance of hybrid algorithms has recently been proven successful, owing to utilizing strengths of global and local search together.[1]-[2]

This paper presents a novel global search algorithm Interstella Search Method (ISM) and its hybridization with Mesh Adaptive Direct Search (MADS). ISM is a population-based search method and is capable of finding diverse target islands of local optima on multimodal function. To evaluate the performance, the proposed method is compared with GA and PSO through the test function. Lastly, the proposed method is applied to design structure of Brushless DC (BLDC) motor to minimize torque ripple.

II. Interstellar Search Method with MADS

To compensate matters for optimal design of electric machine that are mentioned above, role sharing between global and local search is important. Global search algorithm should find diverse target islands exploring overall attractive basins in searching space and local search algorithm should support the fast convergence to accurate target from the target island.

For the global search algorithm to perform its own role effectively, both intensification and diversification strategy should be established well and harmonized effectively. Intensification strategy supports to find target islands in a short time and diversification strategy supports to explore overall searching space without being trapped at local optima. [3]-[4]

From this perspective, ISM adopts some rules supposing the situation that explorers travel throughout space to find the habitable planet. The rules are as below.

a. Explorers start exploration and share information with each other. The three points which have superior fitness are classified as promising planets. The rest of explorer voyages towards promising planets. At this time, the propulsion force and position are as below and illustrated at Fig 1.(a).

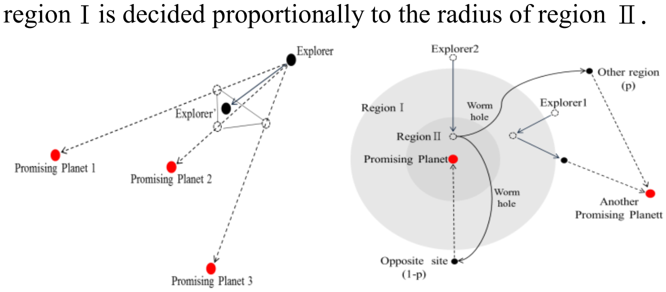
$$F_{ij} = \frac{f(x_{pj}) - f(x_{ei})}{x_{pj} - x_{ei}} \quad x_i^{n+1} = x_i^n + \sum_{j=1}^{3} k_{ij} F_{ij} \qquad (1)$$

Where, F_{ij} represents ith explorer's propulsion force towards jth promising planet, $x_{ei\ or\ pj}^{n}$ represents the position of ith explorer or jth promising planet in nth iteration, and k_{ij} is coefficient between force and velocity as below.

$$k_{ij} = ex(i,j) * den(j) * [\left(\sum_{j=1}^{3} dis(i,j)\right) - dis(i,j)]/2 * \sum_{j=1}^{3} dis(i,j) \qquad (2)$$

Where, $ex(i,j)$ represents ith explorer's record for jth promising planet, $den(j)$ represents superiority density around jth promising planet, and $dis(i,j)$ is distance between ith explorer and jth promising planet. The last terms on the right hand-side is distance ratio. This ratio helps explorers visit the close promising planet preferentially.

b. Region Ⅰ & Ⅱ are formed around promising planet as shown in Fig 1.(b). The radius of region Ⅱ is matched with the length of initial mesh size of MADS, when the radius of region Ⅰ is decided proportionally to the radius of region Ⅱ.



(a) Moving towards promising planet (b) Moving around promising planet

Fig. 1. Rules of ISM

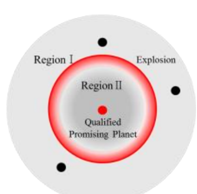
The moment explorers approach Region Ⅰ, they record their own voyage log and move towards another promising planet. Propulsion force towards the visited promising planet is excluded by switching $ex(i,j)$ from 1 to 0. Explorer who approaches promising planet too close to the extent of Region Ⅱ is attracted into black hole around the promising planet and escapes through wormhole which is connected to other region or the opposite side. Their voyage logs are initialized $ex(i,j)$ to 1 when passing the worm hole.

c. On the way to promising planets, if newly discovered planet is superior to the previous one, the worst of previous ones is substituted with a new planet. If the promising planets are too adjacent to extent of region Ⅰ, only the best of that region becomes promising planet and the rest of them are assigned in other regions. To give advantage to the region where many superior points are discovered, $den(j)$ is increased as many as the number of discovered superior planets in that region.

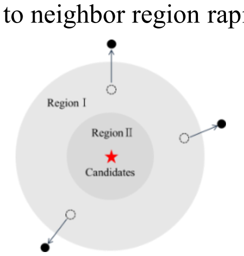
d. When explorers approach promising planet to the extent of Region Ⅰ&Ⅱ, visit count for promising planets is also stacked. If visit count of a promising planet exceeds specific number, the promising planet becomes the candidate to be investigated in detail by main investigator. After planet is registered as a candidate, explosion occurs around the planet and pushes explorers around the point to other region quickly Fig. 2. illustrates the process of explosion and objective function after explosion is as below.

$$if\ dis(i,k) < r_{region\ I},\ f(x_i) = f_w - \delta * dis(i,k) \quad (3)$$

Where $dis(i,k)$ is the distance between ith explorer and kth candidate, $r_{region\ I}$ is the radius of region Ⅰ, f_w is the cost of objective function at worst point and δ is sampling parameter. Forming hill helps explorers spread to neighbor region rapidly.



(a) Registration & Explosion



(b) Spread after explosion

Fig. 2. Description of explosion

If enough candidates are accumulated, local search starts at candidates in sequence of fitness. MADS is used for local optimization algorithm because of its fast convergence performance and simplicity.

III. Comparison with Other Algorithms

As mentioned above, optimal design of electric machine is multimodal problem, which has many local optima. Therefore, we adopted Branin function for test function. Branin function is an example of non-linear multimodal function and has 3 global minimum.

$$f(x,y) = (y - \frac{5.1}{4\pi^2}x^2 + \frac{5}{\pi}x - 6)^2 + 10\left(1 - \frac{1}{8\pi}\right)\cos x + 10 \quad (4)$$
$$Where\ -5 < x < 10, 0 < y < 15$$

To compare precisely, Niching Genetic Algorithm [5] and Fitness Sharing Particle Swarm Optimization (FSPSO) [6] were compared with ISM. These algorithms had been improved to prevent from premature convergence to local solution and maintain diversity by using fitness sharing.

IV. Optimal Design of BLDC Motor

For smooth torque generation, BLDC motor should be designed to develop trapezoidal back-EMF. But non-ideal spatial distribution of the radial air-gap flux density is generated because of geometric problem and it causes vibration and noise. Therefore, in order to reduce vibration and noise, the BLDC motor design must consider harmonic components caused by the non-ideal spatial distortion of the radial flux density. [7]

In this paper, optimal design is conducted by modifying structure of BLDC motor to minimize torque ripple that is relevant with noise and vibration. Design variables are selected to consider the 6th harmonics of tooth ripple. The specification and design variables are shown in Fig. 3.

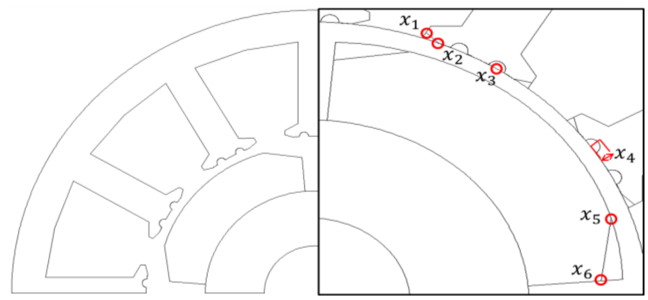


Fig. 3. Structure of BLDC Motor and design variables

V. Conclusion

This paper suggest a novel global optimization algorithm and its hybridization with MADS. ISM algorithm guarantees intensification maintaining diversification by application to Branin function. Optimal design of BLDC motor was conducted using ISM with MADS.

VI. References

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