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Employment of Pigeon Inspired Optimization Algorithm for Pattern Synthesis of Linear Antenna Arrays

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Abstract— **Over a large period of time, the evolutionary as well as social inspired computing practices have modernized the approaches to solve nonlinear problems by their ability to search global optimum results. Numerous engineering glitches as well as problems like antenna array synthesis have been handled with such type of nature-inspired approaches. Despite of several advantages evolutionary algorithms showcase inclination towards converging in a local optimum which in turn degrade their performance while optimizing multimodal search problems. Evolutionary algorithms also lead to premature convergence if the number of iterations goes high while optimizing multi objective functions. Being a bio inspired algorithm, pigeon-inspired optimization showcases superior optimization characteristics as well as rapid convergence. In current work, pigeon-inspired optimization algorithm is employed for synthesizing antenna array. Sidelobe level (SLL) optimization is taken in to consideration for signifying the efficacy of PIO over usual uniform patterns. Simulation-based analysis is done over and again for 5,7,9,11 & 13 elemental linear array. The success rate of the algorithm in handling constrained objectives related to antenna array synthesis has been conferred with significant aftermath from the simulations in respect of convergence plots.**

Keywords—Pigeon inspired optimization algorithm, antenna arrays, optimization;

I. INTRODUCTION

Traditional Algorithms are unable to provide better results while optimizing nonlinear, discontinuous as well as multimodal problems. As in Traditional Algorithms end results are analogous if similar initial points have been considered, it causes diversity deficiencies. To get rid-off above limitations, heuristic as well as metaheuristic algorithms came in to picture. Heuristic algorithms mostly employ trail-and-error scheme for producing new solution, whereas metaheuristic algorithms employ recollection of past solutions for improvising the solution. Basically, metaheuristic algorithms are nothing but higher version heuristic algorithms. Mostly metaheuristic algorithms are basically nature-inspired algorithms which are hinge on Swarm Intelligence (SI). Significance of Swarm intelligence is a swarm founded by several individuals deprived of intelligence showcase intelligent activities through the simple coordination of the individuals among each other. Due to its self-learning capability as well as adaptableness of exterior variations Swarm Intelligence algorithms has been applied in solving various optimization problems. In SI algorithms, the individuals belonging to nature are symbolized by individual points prevailing in the search space. Objective function relative to the problem can be measured as the individuals 'capability to adjust with the environment, whereas individuals' survival of the fittest practice or foraging practice is equivalent to the iterative practice. In practice, a weak feasible solution is being substituted by a strong feasible solution, giving birth to an iterative hunt algorithm categorized with "generation plus test" feature for solving the extreme problems [1]. Based on concept of swarm intelligence research, a variety of optimisation algorithms have been proposed. As researchers are always inspired by Nature, many algorithms have been invented on the basis of swarm behaviour of organisms like fireflies, bees, butterflies, pigeons etc., for discovering solutions of optimization problems. In present era of evolutionary computing several swarm intelligence algorithms also showcase better success rate in optimizing antenna array parameters. Single-element antenna does not possess control on parameters like sidelobe level (SLL), beamwidth (BW) along with beam steering (BS). The major problem lies with frequency dependencies of single-element antennas. Any effort to improve the directivity directly affects operating frequency of the antenna. Operating wavelength along with corresponding frequency gets revised when the length is amplified to boost its directivity. Therefore, single antennas fail to perform in frequency out-and-out applications. The problem can be solved by improving electrical length. At the same time the physical length needs to be kept constant. And this gives birth of antenna array concept. Antenna arrays can control radiation pattern for coveted main and half power BW as well as SLL with suitable alterations of geometrical or electrical assets of the array. Linear as well as planar are mostly two renowned variants of regular array geometry. Circular, elliptical, concentric, rectangular normally come under planar array type. Despite of the shape, array design is mainly directed by geometry-oriented parameters in an array. Therefore, it is likely to transmute a particular design challenge into an optimization problem.

Several swarm intelligence algorithms like genetic algorithm (GA) [2], particle swarm optimization (PSO) [3], firefly [4,5], ant colony optimisation (ACO) [6], Ratio-metric FA [7], GSA-PSO [8] have already showcased their effectiveness in designing antenna arrays. In present work, the research strategy implicates in applying the pigeon-inspired optimization algorithm effectively to Linear antenna array synthesis problems.

II. OPTIMIZATION OF ANTENNA ARRAYS

As antenna arrays showcase several advantages in wireless application, present work is entirely devoted to unique synthesis practices applied on antenna arrays via evolutionary computing tools. Mostly SLL and BW are two main contradictory parameters in antenna array configuration, because if we want to suppress SLL it will enhance the BW and vice versa. Therefore, we can consider antenna array synthesis as an optimization problem for generating narrow BW, while conserving the welfares of low SLL. Mostly the purposes behind array synthesis comprise either governing of SLL or BW or governing both to commendably yield coveted pattern of radiation. Each array element can be regarded as mainly by amplitude (I) as well as phase (ϕ)relative to current excitation along with spacing (d) between the antenna array elements. Varying above mentioned parameters the radiation pattern formed by antenna array could be suitably revised. In radiation pattern the lobe which is to be found in the direction of maximal radiation is known as principal lobe or can be referred as main beam. Rest of the lobes having amplitude lesser than main lobe are known as side lobes. Perfect measure of how effectively the power is being focussed into the principal lobe can be defined as the relative Sidelobe Level (SLL). SLL is nothing but the ratio of the peak sidelobe to the main lobe. We can measure the BW between two first nulls comprising the main beam. Basically, smaller BW causes sharper main beams and helps to avoid interference signals. Where steering parameters such as I, ϕ, and d of antenna array elements are having uniform distribution, we can term them as Uniform antenna arrays and they showcase narrow beam width. Mostly for wireless applications, the required level of SLL has to be maintained below −20 db. Though non-uniform excitation can be treated as good practice for diminishing the SLL but it results in enhanced BW. Hence to attain the benefit of both narrow BW as well as lower SLL, we must control the amplitude excitation (I) along with the inter element spacing (d) for such non-uniform distribution of elements.

III. ARRAY FACTOR FORMULATION FOR LINEAR ARRAY ANTENNA

Array Factor is probably most significant function in entire array theory. Basically, AF is a function of the elemental positions with respect to the array and the weights related to the amplitude as well as phase of excitation current. Array performance could be properly optimized by proper alteration of above said parameters, for achieving coveted characteristics. As per norms of pattern multiplication, we can attain total array field (comprising identical as well as similar elements) by multiplication of field relative to single array element placed at origin with array factor (AF).

A. Problem formulation

Let us consider a 2*N*-element Antenna array having symmetrical distribution along x-axis (Figure 1). Here array factor can be formulated as

$$AF(\phi) = 2\sum_{n=1}^{N} I_n \ \cos[kx_n \ cos(\phi) + \psi_n] \qquad (1)$$

Where *k r*epresents wave number, and I_n , Φ_n and x_n are used for denoting excitation amplitude, phase as well as location of n^{th} array element. The inter element distance is kept equals to $\lambda/4$.

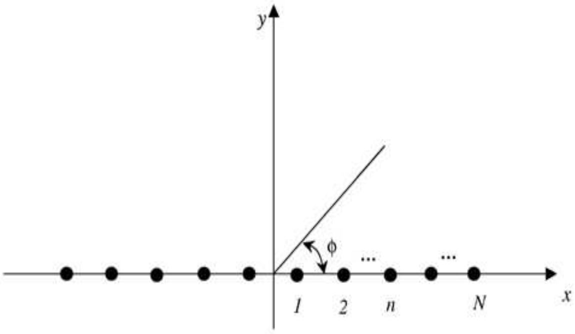

Fig.1. 2*N*-element Antenna array Geometry having symmetrical distribution along *x*-axis

B. Minimizing SL Peak

The PIO algorithm is employed to attain the optimum synthesis ofa2*N*-elementlinear array in order for minimizing SLL in a specific region. We can formulate the fitness function as

$$Fitness = \min(\max\{20\log|AF(\phi)|\})$$

$$subject\ to\ \phi \ \epsilon\ \{[0^0, 76^0]\&[104^0, 180^0]\} \qquad (2)$$

IV.PIO ALGORITHM

From the pages of world history facts and figures show that Pigeons gained popularity among bird species when they were trained and treated by the Egyptians for sending long distance messages. The term “pigeon” was derived from “pipio”, a Latin term, which means “fresh cheeping bird”. Wild pigeons are mostly found around coastal areas where as feral pigeons are very common in places nearby human habitation. During world wars (I & II) Pigeons were used in military on account of their homing behaviour. Pigeons were easily trained as messenger because they can easily discover their homes by utilizing Sun, landmarks as well as earth’s magnetic field. Extensive studies on navigation behaviour of pigeons have proven that during preliminary stage of homing pigeons mostly rely on compass alike navigational tools. During midst age of their journey landmark navigation tool are being preferred. These homing characteristics of pigeons are formulated mathematically with the help of two operators [symmetry 7]. Principles of Compass operator state that using Magneto reception capability pigeons are able to sense Earth’s magnetic field, which in turn helps in formation of map in their brain. Flight direction is adjusted by the pigeons as they consider the altitude of the sun from sea level as compass. Their dependencies on both Sun as well as magnetic Objects come to saturation as pigeons tend to approach their utter destination. Like PSO algorithm, according to PIO algorithm, each pigeon has individual position and velocity Information according to following expressions.

$$V_i^{N_{Count}} = V_i^{N_{count}-1}\ e^{-R\,X\,N_{count}} + rand(X_{globalbest} - X_i^{N_{count}-1}) \tag{3}$$

$$X_i^{N_{count}} = X_i^{N_{count}-1} + V_i^{N_{count}} \tag{4}$$

Where R stands for compass factor $\&rand$ represents a random number both having values between 0 and 1;N_{Count} represents present number of iterarations where as $X_{globalbest}$ stands for optimal postion attained as a result of comparison of positions respective of all pigeons at the end of $N_{Count} - 1$ iteration cycles.Upon reaching coveted number of iterations,the compass operator is made inactive upon making landmark operator active.

As per Landmark operator concept upon nearing destination pigeons start relying more on the neighbouring landmarks. If the landmarks are familiar to them, pigeons tend to fly straightway to the destination. But if the destination is far and landmarks are not familiar then pigeons tend to follow other pigeons that happen to be familiar. In every iteration, the pigeons count is halved by neglecting the pigeons which are quite far from the ultimate destination as those pigeons are not familiar with the neighbouring landmarks as well as no longer are unable distinguish the correct route.$X_{central}$represents central position of rest of the pigeons and can be treated as a landmark or we can say as a reference with respect to flight direction. Meanwhile position related to ith pigeon can be updated with the help of following expressions.

$$X_{central}^{N_{Count}-1} = \frac{\sum_{i=1}^{N^{N_{Count}-1}} X_i^{N_{count}-1}\ F(X_i^{N_{count}-1})}{N^{N_{Count}-1}\sum_{i=1}^{N^{N_{Count}-1}} F(X_i^{N_{count}-1})} \tag{5}$$

$$N^{N_{Count}} = \frac{N^{N_{Count}-1}}{2} \tag{6}$$

$$X_i = X_i^{N_{count}-1} + rand(X_{central}^{N_{Count}-1} - X_i^{N_{count}-1}) \tag{7}$$

Where

$$F(X_i^{N_{count}-1}) = \begin{cases} \dfrac{1}{fitness(X_i^{N_{count}-1}) + \varepsilon'}, & For\ Mimization\ Problems \\ fitness(X_i^{N_{count}-1}), & For\ Maximization\ Problems \end{cases}$$

ε' is a small positive number and effectiveness of landmark operator comes to an end once maximal number of iterations has been achieved.

V. DESIGN EXAMPLE

Linear antenna arrays composed of 5, 7, 9,11and 13 isotropic radiating elements distributed with an inter-element spacing of **λ**/4, have been taken in to consideration for present optimization approach. PIO has been employed to attain deeper nulls as well as to diminish the SLLs. PIO has been executed with 400 iterations by considering population size to be fixed at 20. The program is being written in MATLAB platform having version7.8.0(R2009a) on a 3.00 GHz core (TM) 2 duo processor with 2 GB RAM.

Design example illustrates the synthesis of a 5,7,9,11&13 element array to attain minimum peak of side lobe in the expanse of ϕ= [0˚, 74˚] and ϕ= [106˚, 180˚]. PIO optimized resultant array patterns are being presented (Fig. 2-6) along with the uniformly excited array pattern. From the results improvement in the reduction of side lobes employing PIO is pretty much visible as compared to uniformly excited array. Side lobe levels of proposed PIO optimized array arrangements (5,7,9,11&13 element) have been represented in tabular format (Table 1).

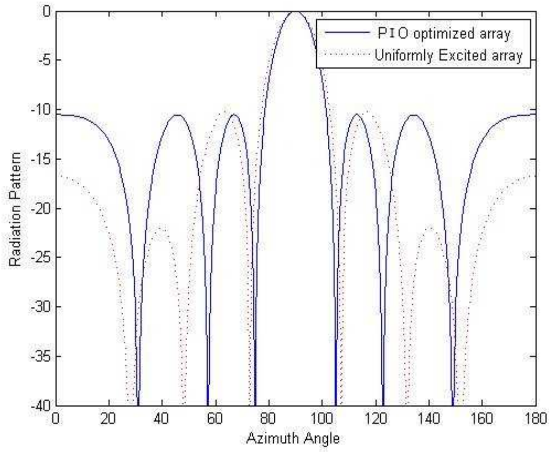

Fig. 2. Normalized array pattern of 5 element Linear array Optimized via PIO.

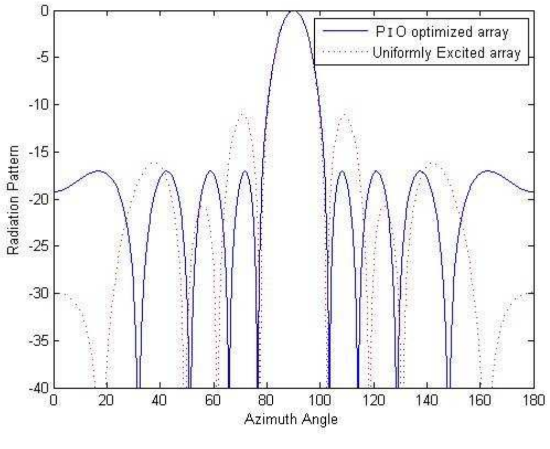

Fig. 3. Normalized array pattern of 7 element Linear array Optimized via PIO.

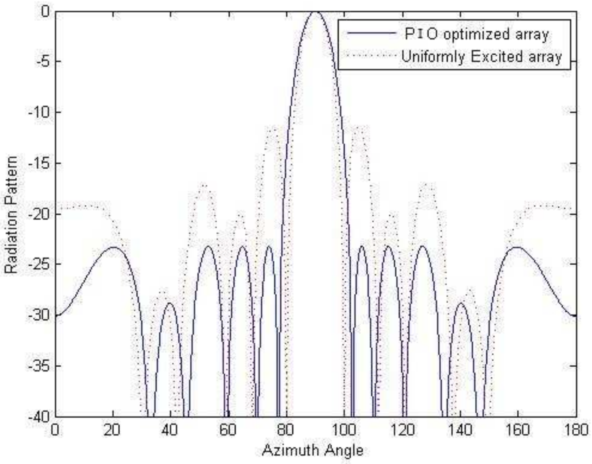

Fig. 4. Normalized array pattern of 9 element Linear array Optimized via PIO.

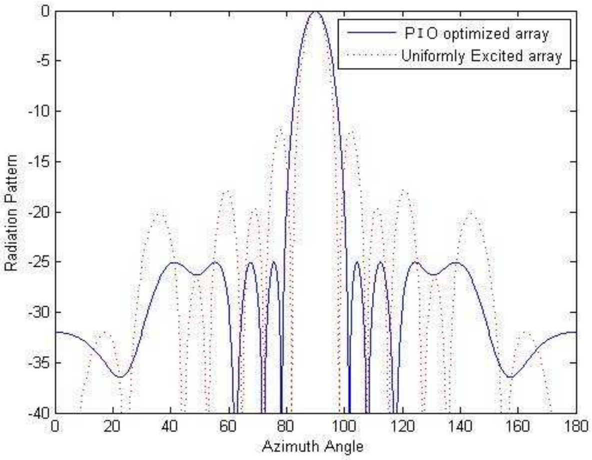

Fig. 5. Normalized array pattern of 11 element Linear array Optimized via PIO.

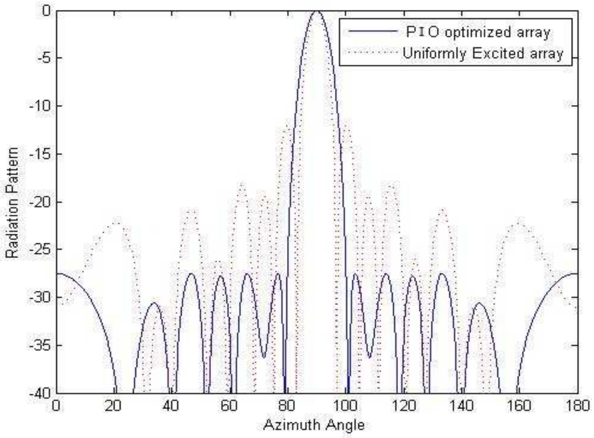

Fig. 6. Normalized array pattern of 13 element Linear array Optimized via PIO

TABLE 1. Comparison of SLL & FNBW values for PIO optimized Linear array sets

Set No.	**Number of elements**	**SLL**	**FNBW**
I	5	-10.52 dB	26
II	7	−17.04 dB	23
III	9	−23.23 dB	21
IV	11	−25.30 dB	20
V	13	−27.70 dB	19

A. Consequences of varying the population size

The final fitness outcomes (minimum SLLs) are being presented for distinct varieties of populations (particles) in Table 2(a) & 2(b). PIO algorithm has been executed 15 times for different sets of populations such as 15, 30, 50 and 70 while considering other parameters to be constant. Table2a &2b signifies that fitness value shrinks lightly when number of particles rises from 50 to 70 except the case for 7 element array.

TABLE. 2(a)

Fitness value (PIO)	**Fitness value obtained for 5 element LAA**			**Fitness value obtained for 7 element LAA**			**Fitness value obtained for 9 element LAA**		
	Number of Particles			Number of Particles			Number of Particles		
	30	50	70	30	50	70	30	50	70
Best	-10.50	-10.51	**-10.52**	**-17.33**	-17.22	-17.22	-23.75	-23.76	**-24.09**

TABLE. 2(b)

Fitness value (PIO)	**Fitness value obtained for 11 element LAA**			**Fitness value obtained for 13 element LAA**		
	Number of Particles			Number of Particles		
	30	50	70	30	50	70
Best	-30.41	-29.97	-30.55	-37.95	-35.25	-37.77

Table 2a & 2b. Fitness values of PIO optimized LAA as per deviation in population size

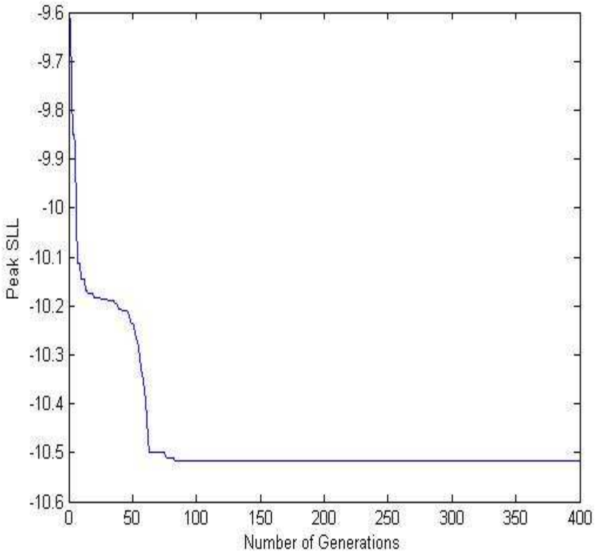

Fig. 7a. Convergence profile for 5 element Linear array using PIO

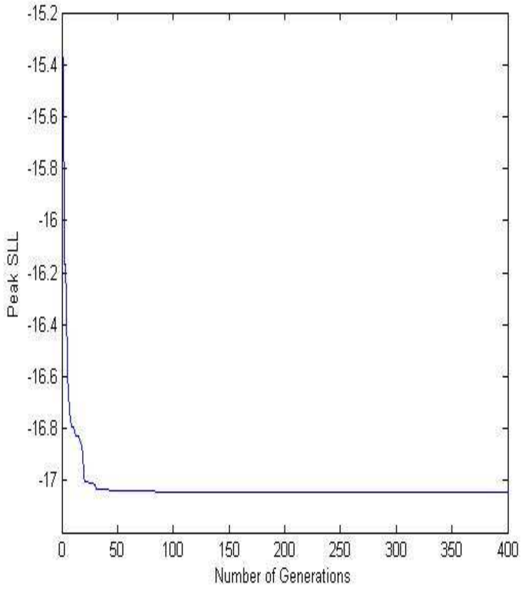

Fig. 7b. Convergence profile for 7 element Linear array using PIO

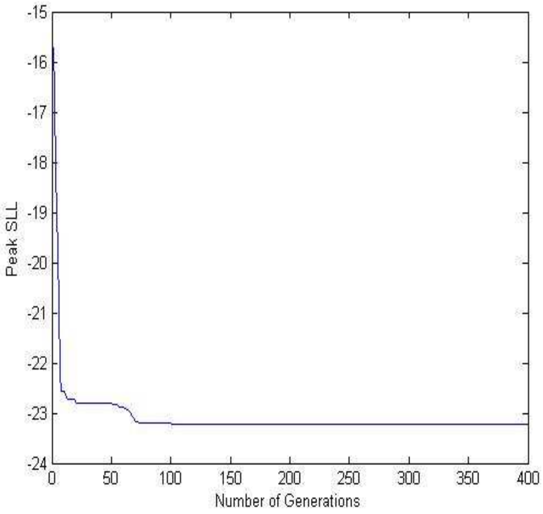

Fig. 7c. Convergence profile for 9 element Linear array using PIO

VI. CONCLUSION

Pigeon-inspired optimization algorithm is successfully applied in the field of antenna array optimization. Five different sets of linear antenna array design instances are presented to validate the effectiveness of PIO. The PIO has proven its constancy in providing solutions against antenna array synthesis glitches in terms of computation time as well as convergence characteristics. Though the present work is all about finding solution for single-objective problem but in due course it is possible to use same approach for finding solutions for multi-objective optimization. Future research directions also suggest improvements at the algorithm level, by imposing adjustment characteristics to PIO algorithm, for enhancing optimization capability of the algorithm

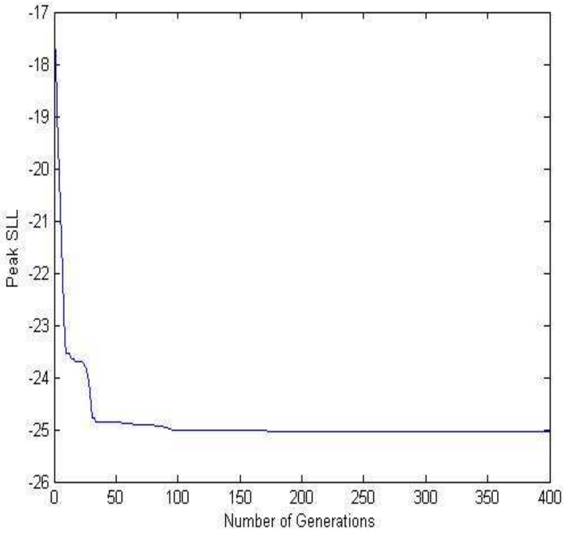

Fig. 7d. Convergence profile for 11 element Linear array using PIO

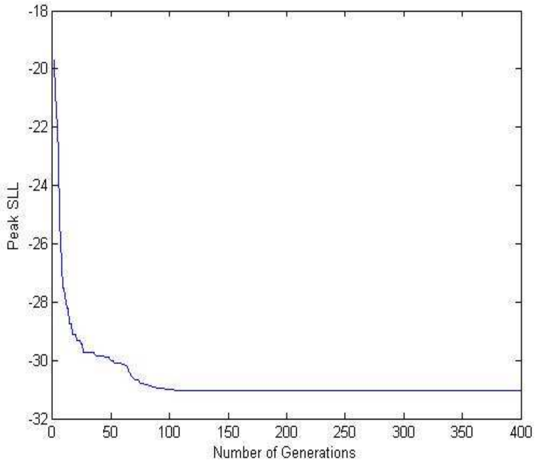

Fig. 7e. Convergence profile for 13 element Linear array using PIO

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