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Introduction to Multiple Beams Adaptive Linear Array Using Genetic Algorithm

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Abstract: ***In this paper, Genetic algorithm, Dolph-Tschebyscheff distribution and the frequency shifting property of Fourier transform are used to calculate the complex excitations, i.e. amplitudes and phases of adaptive antenna arrays. Genetic algorithm adjusts some of the least significant bits of the beam steering phase shifters to minimize total output power in unwanted direction. Using small adaptive phase values results in the minor deviation of main lobe direction and perturbations in the side lobe level. Various results are presented to demonstrate the advantages and limitations of this approach. Battlefield electromagnetic environment has become more and more complex under the background of information war. Strong interfering signals have seriously affected the quality of communication and reliability of information. To weaken or even eliminate the effect of the unwanted signal to the wanted one, genetic algorithm (GA) is utilized to optimize element current amplitudes in obtaining the needed radiation pattern of adaptive linear array antenna under intensive interference environment. Details on structure of the system, radiation pattern formulation, and application of the genetic algorithm are given, and simulation examples are also demonstrated to show the effectiveness of the GA approach. advantages are such that the optimized amplitudes can be directly used in the engineering without further discretization, and that the ratio of maximum amplitude to minimum one is moderate which makes it easy to feed the antenna.***

Keywords: Robots, Zigbee, Transceiver, CMOS, MCU.

1. Introduction

Wireless communication technologies have experienced fast growth in recent years. The latest mobile devices offer multi-bandwidth services and to enable this, new technologies have to be developed. Spatial processing is considered the last frontier in the battle for improved cellular systems and smart antennas are emerging as the enabling technique. The use of adaptive antenna arrays in mobile handsets can help eliminate co-channel interference and multi-access interference among other problems. These breed of antennas are able to radiate power towards a desired angular sector, thus, avoiding interference with undesired devices. The number, geometrical arrangement, and relative amplitude and phases of the array elements depend on the angular pattern that must be achieved. By changing the relative phases of array elements, a process called steering, an array is capable of focus towards a particular direction. Due to the amazing development of computers, the application of numerical optimization techniques to antenna design has become possible. Among these techniques, bioinspired algorithms like the Particle Swarm Optimization (PSO) [1] have been found to be effective in optimizing difficult multidimensional problems in a variety of fields [2]. This technique has proven to be successful for antenna design, as presented in [3], [4], [5] and shown to outperform, in certain cases, other optimization methods [6]. Particle Swarm Optimization is based on the behaviour of groups of living creatures like a swarm of bees. Their goal is to find the location with the highest density of flowers by randomly flying over the field. Each bee can remember the location where it found the most flowers, and by dancing in the air, it can communicate this information to other bees.

Occasionally, one bee may fly over a place with more flowers than had been discovered by any bee in the swarm. Over time, more bees end up flying closer and closer to the best patch of the field. Soon, all the bees swarm around this point. Previous work on the field of antenna array analysis and design have been presented in [4], where the relative position of the antenna elements has been optimized by the PSO technique to obtain minimum Side-Lobe Levels (SLL) and nulls towards the undesired directions. The PSO algorithm has successfully been applied as well to design other kinds of antennas like circular antenna arrays [7] by setting the distance between the elements. However, for the case of smart antennas, the position of the antenna elements is fixed so the relative displacement can not be changed. To determine the shape of the radiation pattern, another characteristic of the array must be adjusted, for example the excitation phase of each individual element. Phase shifters connected to the antennas can be used to cancel interference by placing nulls on the directions of the interfering sources. This was proposed in [8] and was accomplished by using Memetic Algorithms.

2. Literature Survey

"Phase–only Adaptive Nulling with a Genetic Algorithm"

This paper describes a new approach to adaptive phase-only nulling with phased arrays. A genetic algorithm adjusts some of the least significant bits of the beam steering phase shifters in order to minimize the total output power. Using a few bits for nulling speeds convergence of the algorithm and limits pattern distortions. Various results are presented to show the advantages and limitations of this approach.

"Optimizing Beam Pattern of adaptive Linear Phase array Antennas using Local Genetic algorithm"
In this paper, an innovative optimal adaptive antenna technique based on phase shift perturbation method is proposed. Local genetic algorithms are used to search the optimal weighting vector of the phase shift perturbations for array factor. The design for an optimal radiation pattern of an adaptive antenna can not only adjustably suppress interferers

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by placing nulls at the directions of the interfering sources but also provide a maximum main lobe in the direction of the desired signal at the same time. In order to achieve this goal, a new convergent method referred as the two-way convergent method for local genetic algorithms is proposed. The local genetic algorithm combines genetic algorithm and local search heuristics to solve combinatorial optimization problems.

"Side lobe level optimization using modified genetic algorithm"

The sidelobe level (SLL) of a linear array is optimized using modified continuous genetic algorithms (GA) in this work. The amplitude and phase of the current as well as the separation of the antennas are all taken as variables to be controlled. The results of the design using modified GA versions are compared with other methods. Two design problems were studied using several continuous modified GA versions and the results are presented as several plots. As a final example, the design specifications for an array with 200 elements is given. The effectiveness and advantages of the modified GA versions is outlined.

"Null steering in phased arrays by controlling the element positions"

Null steering methods usually involve costly and complicated amplitude and/or phase control systems. A technique is presented for null steering based on the element position perturbations. The technique frees the phase shifters to be used solely for steering the main beam toward the direction of the desired signal. It also removes the limitations of the other techniques by independently steering the main beam and the nulls to arbitrary independent directions. This technique is also capable of obtaining sidelobe cancellation and wideband signal rejection.

"Array pattern nulling by element position perturbations using a genetic algorithm"

A genetic algorithm has been used for null steering in phased and adaptive arrays. It has been shown that it is possible to steer the array nulls precisely to the required interference directions and to achieve any prescribed null depths. A comparison with the results obtained from the analytic solution shows the advantages of using the genetic algorithm for null steering in linear array patterns.

"An introduction to genetic algorithms for electromagnetics"

This article is a tutorial on using genetic algorithms to optimize antenna and scattering patterns. Genetic algorithms are "global" numerical-optimization methods, patterned after the natural processes of genetic recombination and evolution. The algorithms encode each parameter into binary sequences, called a gene, and a set of genes is a chromosome. These chromosomes undergo natural selection, mating, and mutation, to arrive at the final optimal solution. After providing a detailed explanation of how a genetic algorithm works, and a listing of a MATLAB code, the article presents three examples. These examples demonstrate how to optimize antenna patterns and backscattering radar-cross-section patterns. Finally, additional details about algorithm design are given.

3. Design and Implementation

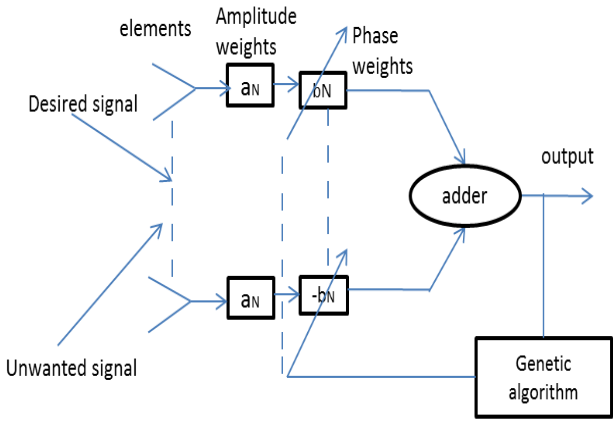


Figure 1: An adaptive linear array with phase perturbations using Genetic algorithm

For a linear array of 2N equi-spaced sensor elements as in Fig.1, an interfering signal with wavelength λ impinges on any two adjacent sensor elements by a distance d and from a direction θ with respect to array normal. The array factor for far field, is given by

$$AF(\theta) = \sum_{n=1}^{2N} w_n e^{j(n-1)\psi} \text{ .... (1)}$$

If the reference point is at the physical center of the array, the array factor becomes

$$AF(\theta) = \sum_{n=1}^{2N} w_n e^{j(n-N-0.5)\psi}$$

$$= \sum_{n=1}^{2N} a_n e^{j[(n-N-0.5)\psi+bn]} \text{.................... (2)}$$

Where 2N = number of elements,
$w_n = a_n e^{jbn}$ complex array weights at element n,
a_n= amplitude weight at element n
b_n = phase shifter weight at element n
ψ= kd sinθ+ ϕ
θ=an incidence angle of interfering signal or desired signal from the array normal.
ϕ =beam steering phase;

The equation (2) includes imaginary part so that it is not suitable for using optimization search. If amplitude weights are constant and phase shift weights are odd symmetry, the equation (2) can be simplified to[2]

$$AF(\theta)=2\sum_{n=1}^{N} a_n \cos[(n-0.5)\psi+b_n] \text{.................. (3)}$$

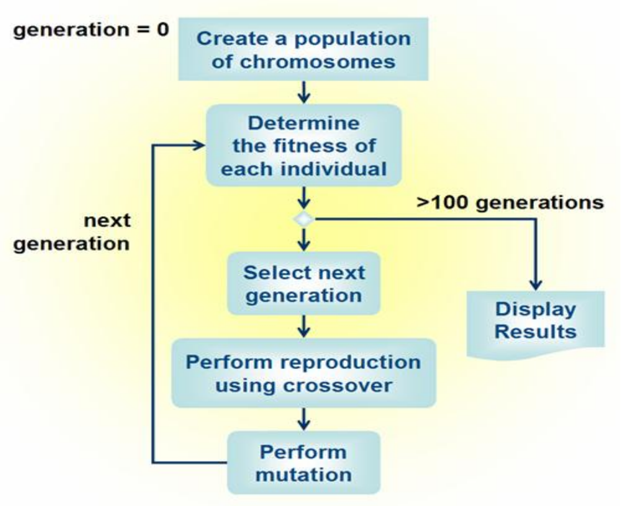
The equation (3) can be written in normalized form as follows:

$$AF_n(\theta)= \frac{1}{N}\sum_{n=1}^{N} a_n \cos[(n-0.5)\psi+b_n]$$

The array factor, given by(3), describes the model of the radiation pattern and suitable for optimal solution search. The steering phase (n-0.5)ϕ is calculated first and then nulling phase b_n is found. The digital phase shifters have 8 bits. The cost of the phase shifter depends on the size of the chip. So the number of bits needed for the phase shifter is to be as small as possible. Here the position of 5^{th} , 6^{th} , and 7^{th} bits are used to nullify the side lobes rather than last sequence bits as done previously

4. System Design

The system is designed as shown in Figure 2.



5. Methodologies

5.1 Antenna Structure and Radiation Pattern

For an adaptive linear array antenna of 2N equispaced elements, each with an element factor sin_, an interfering signal with wavelength _ impinges on any two adjacent elements by a distance d, and from a direction _ with respect to x-axis, as shown in Fig. 1. The radiation pattern of the array antenna for far field using amplitude perturbations is given by

$$F(\varphi) = 20\lg\left|\frac{\sin\varphi \sum_{n=1}^{2N} I_n e^{j\psi_n}}{\sum_{n=1}^{2N} I_n}\right|.$$

Where 2N=number of elements;
In=amplitude weight at element n;
=incident angle of interfering or desired signals; and
n =phase shift of the nth element with regard to the wavelength _ in free space, the incident angle _, and the reference point.
Given that the number of elements are even, the reference point is at the physical center of the array, and the amplitudes are symmetric about the center of the array elements, that is, I-n=In, (n=1, 2, _, N), as in Fig. 1, the radiation pattern in (1) can be further simplified as:

$$F(\varphi) = 20\lg\left|\frac{\sin\varphi \sum_{n=1}^{N} I_n \cos(kd_n \cos\varphi)}{\sum_{n=1}^{N} I_n}\right|$$

Where is the distance from element n to the center of the array. This representation of the element spacing insures that element n+1 is closer to the array center than element n for the "positively" numbered part of the array. Obviously, the radiation pattern is symmetric in this case, that is, F(_)= F(180__). It is worth reminding that F(_) is implicitly also a function of k, the kth chromosome in the current generation of a GA, because In is decided by _ k, as shown later in (3).

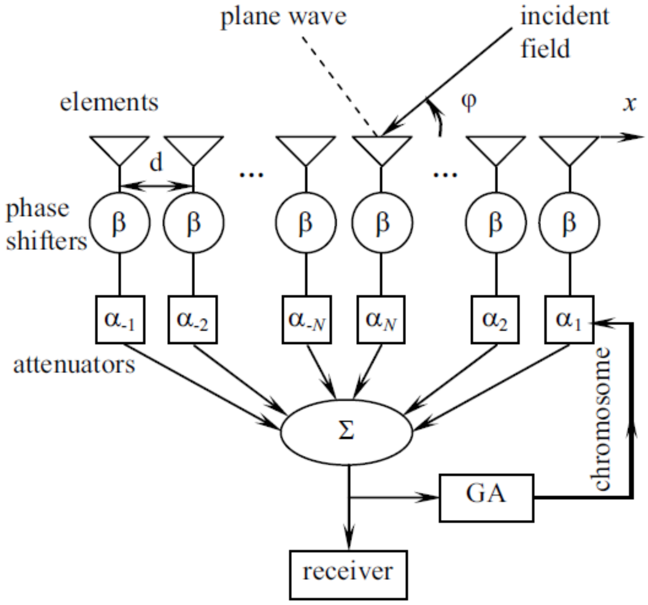


Figure 3

5.2 Objective Function Selection

Objective function selection is a key step in genetic algorithm because it is dependent on the problem to be optimized. To maintain low maximum sidelobe level and compress the interferingsignal with high intensity as well, the objective function of genetic algorithm is selected as

$$f(\upsilon_k) = \omega_1 |MSLL(\upsilon_k) - SLVL| + \omega_2 \sum_{i=1}^{M} \gamma_i |F(\varphi_i^{NL}, \upsilon_k) - NLVL_i|$$

Where _ k is the kth chromosome in the current generation of the GA, SLVL is expectation value of the maximum sidelobe level, MSLL _ max{F(_),_ _S}, in which S denotes the sidelobe region, and it is discretized by one degree in numerical simulation. Given that the first-null beam width is 2 _ 0, the sidelobe region can be expressed as bellow:

Possibly, there exist simultaneously several interfering signals from M directions, say, , i□1, 2, ..., M, and is the expected value of null depth level to sufficiently suppress unwanted signal from direction are all weighting factors. In the simulation, 1, =1, _2 =0.2, and all _'s are set equal to 1.

5.3 Fitness Function

The fitness function is virtually a domain transformation from objective value to fitness value. In the framework of GA, fitness function may not always be the same as objective function. Appropriate fitness function helps not only working out the correct answer to the primary problem but also improving the convergence rate the algorithms. Because roulette wheel approach, one of the fitness proportional selection methods, is especially adopted, the fitness function is given as below:

$$g(\upsilon_k) = \max(fitConst, fitMax - fitMulti \times f(\upsilon_k))$$

In the simulation, fitConst=0.001, fitMulti=100, and fitMax= 5000. And elitist selection method is combined with this approach to preserve the best chromosome in the next generation and overcome the stochastic errors of sampling.

5.4 Optimizing Beam Pattern of Linear Adaptive Phase Array Antenna

High quality and good efficiency are asked for the modern wireless communication. Antennas in base station use omnidirectional or sectored pattern, which could cause the power waste in unexpected direction and interference for the others. Radiation pattern nulling techniques suppress undesired interfering signals [1-2]. But, a perfect idea to solve the problem is to use the adaptive antenna. An adaptive antenna system not only suppresses interference by placing a null in the direction of the interfering source, but also adjusts the direction of main lobe toward the user at the same time. The adaptive antenna system can provide a greater coverage area for each cell site, higher rejection of interference and cost-down benefit of equipment. Optimal radiation pattern techniques are very important to cancel undesired interference and enhance desired signal. A perturbation method consists of small perturbations in the element phases to obtain the optimal radiation pattern, which has got much attention. In this study, a search procedure based on the PSO algorithm is used to obtain the required perturbations for the designed optimal radiation patterns, whose procedure for the proposed optimal radiation pattern techniques provides an iterative solution [3-5].

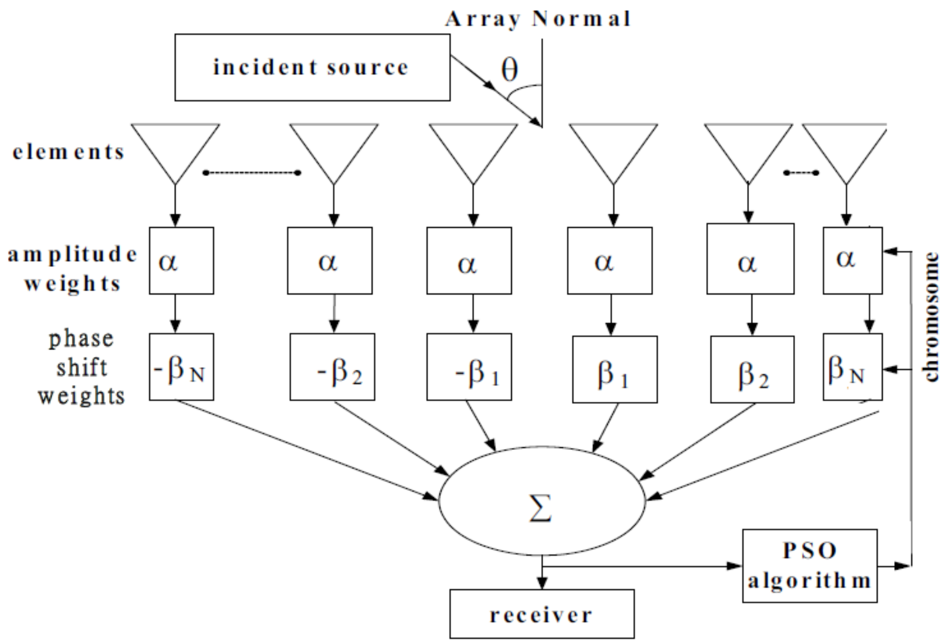


Figure 4

6. Results

In this design, the necessary parameters of the PSO algorithm are defined as follows: the population size P equals 300; the maximum number of generation equals 600; the maximum value of inertia weight w is 0.8; the minimum value of inertia weight w is 0.3. ; The population size, maximum number of generation, the maximum value of inertia weight, the minimum value of inertia weight, the acceleration constants and the maximum speed of particle are specified before the implementation of the algorithm. Their values definitely affect the process of optimal solution search and results. These parameters affect the optimization processes, and the results of radiation pattern design problems are presented. In this problem, a linear antenna array is composed of 20 isotropic elements. So, N = 10. N is variable number. The distance d of two adjacent elements is half of . The technique features are by using phase shift perturbations. Amplitude weights are constant and phase shift weights are in odd symmetry. The value of is constant and equal to 1.

The value of n is set between - and in rad. The unit of n is rad. Example

In this example, with respect to array normal, the interfering source directions are from -300 , and the desired signal direction is from 300 The PSO algorithm is going to stop after 600 iterations. The best weighting vector is derived. The result is listed in Table 1. The optimal beam pattern has been derived. The beam pattern in Cartesian coordinates is shown in Figure 4. The SIN = 67 dB so that the interfering sources can be ignored. For the optimization design, the optimal beam patterns can have been achieved.

The beam pattern in polar coordinates is shown in Figure 5 and 6.

β_1= -2.688
β_2 = -0.691
β_3 = -2.757
β_4= 0.458
β_5= -1.539
β_6= 0.509
β_7 = -1.966
β_8= -0.031
β_9 = -1.689
β_{10} = 2.977

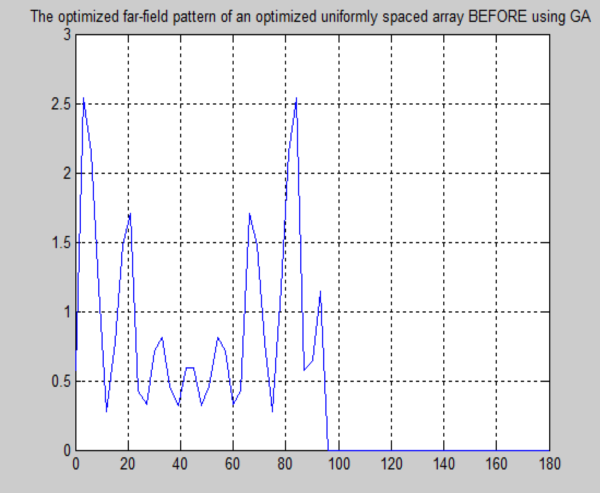


Figure 5: Optimal radiation pattern of adaptive antenna

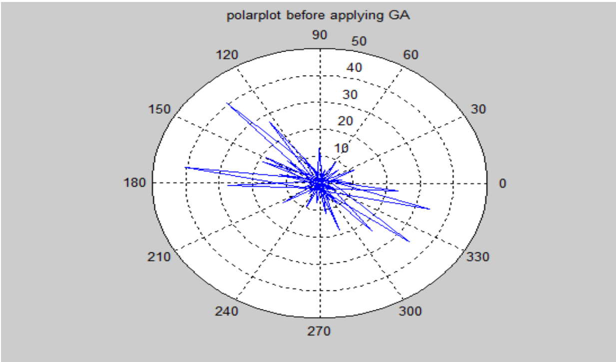


Figure 6: Radiation pattern of adaptive antenna in polar coordinate (scaled in dB)

7. Conclusion and Future Work

The Adaptive array of smart antenna is considered. The algorithm converged at around 50 iterations. It performed well for two undesired signals that are located at 80^0 and 160^0. The 50-elements low side lobe array showed fast convergence, deep nulling capability, and small pattern distortions. Using only a few (5,6,7th positions) of least significant bits and small phase values for the MSB are the key to the algorithm performance. As the number of phase bits are increased the radiation pattern is modified more drastically at the desired main beam and side lobes. This algorithm has the important advantage of being simple to implement on existing phased arrays. Disadvantages include little success at nulling interference entering a quantization side lobe and interference at symmetric angles about the main beam. The above method can be applied to different types of adaptive arrays with different shapes.Genetic algorithm is presented to optimize element current amplitudes to obtain the needed radiation pattern. Some advantages are worth noticing that the optimized amplitudes can be directly used in the engineering without further discretization because the searching precision is set the same as the digital attenuators with special technique, and that the ratio of maximum amplitude to minimum one is moderate which makes it easy to feed the antenna. The synthesized array pattern has deep nulls steered in the interference direction and main beam directed towards the desired signal with the prescribed side lobe level and null depth level in the side lobe region. Future study will be focused on skills to improve the convergence rate of the problem of this kind.

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