Hybrid genetic programming with modified conjugate direction search for 3D metamaterial design

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***Abstract*—Hybridization of Genetic Programming and global low-level optimizer, namely Genetic Algorithm was previously developed. With the aim of improving computational efficiency, conjugate direction search method is modified and proposed as a new low-level optimizer for upper level Genetic Programming. In order to demonstrate computational efficiency, Genetic Programming and two low-level optimizers are employed to design broadband, low frequency ground plane (225 MHz- 450 MHz). When applying optimizers on a single processor, preliminary results show that optimized unit cell found by new low level optimizer has a better reflection magnitude (at least 0.8 over the frequency range) than the one found by Genetic Algorithm (as low as 0.25 over the frequency band). Details of proposed method will be presented and discussed in the paper.**

Keywords—Genetic Programming, conjugate direction search, artificial magnetic conductor, antenna ground plane.

I. INTRODUCTION

Metamaterial has been applied intensively in microwave area, one of its important applications is to enhance the gain while miniaturizing the antenna [1]. Perfect magnetic conductor (PMC) reflects the fields in-phase, thus antenna gain can be increased by putting the antenna directly on top and frequency dependent spacing is eliminated for the case of perfect electric conductor (PEC). The physical realization of PMC is artificial magnetic conductor (AMC) ground plane, which consists of low-loss dielectric substrate material and 3D patterning. AMC ground plane can be modeled using unit cell with boundary condition in the x and y dimensions and full-wave electromagnetic simulator, as shown in figure 1.

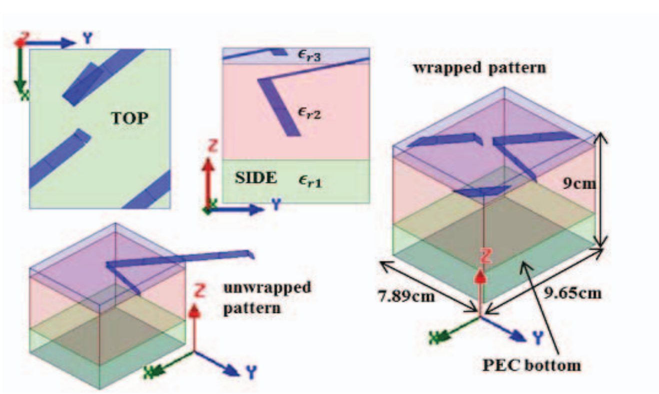

Fig. 1. An example of AMC ground plane unit cell [5]

In order to have a compact and true 3D-metamaterial design, Genetic Programming (GP) is used to explore the complex 3D design space. GP is an evolutionary computational method which is able to synthesize new topologies and optimizing design variables, while only requiring design specifications. In GP, the solution is represented as a computer program, which in this case is metamaterial unit cell [2][3]. Although GP is capable of both topology synthesis and optimization, the overall process can be accelerated by the use of low-level optimizer. Regarding this hybrid approach, GP creates and modifies topologies at the upper level and each design is optimized separately at the lower level. Previous studies have been done with Genetic Algorithm (GA) [4], this paper introduces a modified conjugate direction search as low-level optimizer, and new method of parallelization, which can speed up the design process. Section II provides the details of low-level optimizer and hybridization technique and section III shows preliminary results.

II. DESCRIPTION OF HYBRIDIZATION TECHNIQUE

A. Parallelization and new low-level optimizer

In [4], original GP has been modified to improve performance by the addition of GA as low-level optimizer and parallelization. In this proposed technique, as illustrated in figure 2, parallelization is implemented at both GP and low-level optimizer levels. Each GP program is optimized separately and the results are inserted into the original GP program tree and returned to GP. Variables to include in low-level optimizer are extracted from a GP program tree: unit cell size (x and y), substrate thickness and dielectric, pattern scale, pattern rotation, turning the pattern ON/OFF, pattern starting location and slope (u_x, u_y, u_z), pattern diameter and all the red trees within the blue sub-trees (blue sub-trees are responsible for drawing patterns [2]). For one individual GP program tree the number of variables is constant, it varies throughout population depending on how many substrate layers and patterns a GP member has.

To evaluate how well the design meets the high-level specifications, requirements for reflection phase is varying within the region $[-90^o, 90^o]$ and reflection amplitude must be close to 1 as much as possible. All these constraints are compressed in a representative performance score P where a lower value is considered better [2]. Assuming one GP

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program has n variables to optimize, the aim of low-level optimizer is to minimize function $P(x_1, x_2, \ldots, x_n)$. The minimization of function P can be achieved by conjugate direction search method. This approach starts with a random point and the objective is to find correct direction to global minima of P.

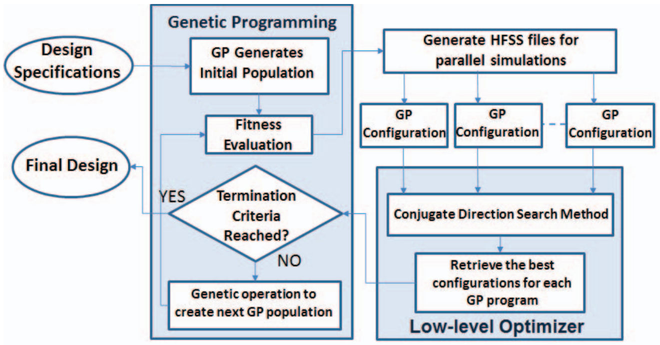

Fig. 2. Flow chart of hyridization technique including parallelization

B. *Modified method with stopping criteria*

This algorithm can be divided into two main parts: *exploration* and *progression.* The search procedure starts with a random intial point $x0$ and an uniform stepsize d representing search direction. In *exploration,* for each dimension of variable, the direction is adapted to move towards the global minima by using quadratic interpolation. The details of how quadratic interpolation select the direction by function evaluations can be found in [5]. When *exploration* is finished, the new optimal point and new search direction are updated and *progression* is started. The line search continues with the vector found in *exploration* and corrects it by quadratic interpolation. In the original method, both *exploration* and *progression* are replicated several times, that makes computational effort considerably expensive if the position of variable keeps staying around local minima. In order to avoid that, stopping conditions are imposed in both *exploration* and *progression*.

```
Condition 1:
If nS > n1
   For i = 1:3
        If min(P) − P(nS − i) > perf
                Continue the search
        Else
                Stop the search
        End
   End
End

Condition 2:
If nS > n2
   Stop the search
End
```

nS is number of evaluations, $n_2 = 0.4n$ in *exploration* and $n_2 = 0.6n$ in *progression,* $n_1 = n_2 - 10$ in both cases. $perf = 5$ is a pre-defined number in condition 1, which means if there is no improvement in 5 recent evaluations, the search is terminated. In condition 2, if after a certain number of evaluations, the algorithm is stopped and it returns the optimized variable. Since the performance of line search method depends on the starting point, restarting condition is also imposed in this research. If the random initial point has too high fitness score, it will be dimissed and replaced by a better one.

III. PRELIMINARY RESULTS

In order to test the efficiency of proposed method, a GP program tree is extracted from the initial population at the upper level and it is optimized on a single processor. The optimal design found by new conjugate line search method has total thickness of 9 cm and parameters of substrate layers are as follows: $t_1 = 20.8; t_2 = 69.2; \epsilon_{r_1} = 12.16; \epsilon_{r_2} = 4.5$.

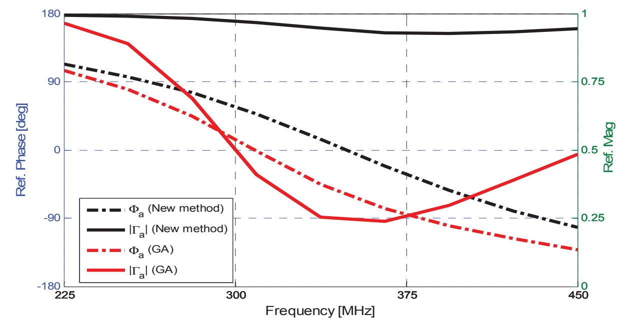

Fig. 3. Amplitude and phase of reflection coefficient of AMC ground plane

The reflection response to an x-polarized plane wave is shown figure 3. As it may be seen, the best configuration found by new line search method has a better reflection magnitude than the one found by GA low level-optimizer. The lowest value of reflection magnitude in GA case is approximately 0.25 while in the case of new method, amplitude of reflection coefficient is always above 0.8. In this specific case, number of individuals in GA population is 25 and maximum number of iterations is 10. If more computation efforts are spent on GP upper level and GA low-level optimizer, it is shown that reflection coefficient is brought into the target range of -90^o to $+90^o$ while the issues with magnitude continued [3] [4]. Both configurations found by the two implemented low-level optimizers still have reflection phase slightly out of the range $[-90^o, 90^o]$ and more updated results will be shown in the conference.

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