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Design Optimization of Loud-Speaker Using Cuckoo Optimization Algorithm

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Abstract
In this paper, Cuckoo optimization algorithm has been used to optimize the design of a loud speaker that has been modeled by using 16 design variables. The design problem is to minimize the overall volume of the speaker while maintaining at least minimum prescribed magnetic field intensity. The condition has been modeled as an inequality constraint, in which the flux density is required to be larger than a given fixed value.

Keywords
Cuckoo Optimization Algorithm (COA), Loud Speaker Design, Optimization.

I. Introduction

A number of researchers have contributed in the field of loudspeaker design optimization, which is a complex problem involving a number of design variables. Felipe Campelo [1] has modelled loudspeaker using 16 variables. His paper is basically in Spanish language & describes the various software and procedures required for using his model. Mehak et. al. have used an artificial bee optimization algorithm to solve the problem of loudspeaker design [2].
Leandro dos S.Coelho [3] presents the differential evolution technique for loudspeaker design optimization. In this paper loudspeaker design problem has been discussed as a 17 variable problem, design problem is to minimize the volume of material used in the construction of the loudspeaker while maintaining at least some minimum prescribed value for the magnetic flux density in the air gap, so as to allow the loudspeaker to work properly.
R.Ierusalimschy et.al. [4] provide the basic Lua script for loudspeaker design. Loudspeaker design has been developed in lua scripting language and this program is fed to the finite element method magnetics. Lua combines simple procedural syntax with powerful data description constructs based on associative arrays and extensible semantics. Lua is dynamically typed, runs by interpreting byte code for a register-based virtual machine, and has automatic memory management with incremental garbage collection, making it ideal for configuration, scripting, and rapid prototyping.
D. Meeker et. al. provides [5] the basics of finite program for defining, solving, and post processing 2D planar and axisymmetric problems of magneto element method magnetics (FEMM). FEMM is a Windows statics, eddy currents, and electrostatics via the Finite Element Method. FEMM is a suite of programs for solving low frequency electromagnetic problems on two-dimensional planar and axisymmetric domains. The program currently addresses linear/nonlinear magneto- static problems, linear/nonlinear time harmonic magnetic problems, linear electrostatic problems, and steady-state heat flow problems.
Dong-Wook Kim et.al [6], have modeled the loudspeaker using 12 variables and the design is optimized using the Sampling-based Sensitivity Information of a Hyper-spherical Local Window. The objective function and the constraint mechanism has been the same as taken in other papers i.e. the design problem remain to minimize volume of the material used while maintaining a specific flux density.
Xin-she Yang and Suash Deb [7] have explained the basics of cuckoo search algorithm. They had developed this algorithm in 2009. Their paper presents a study using some standard test functions and newly designed stochastic test functions. In [78], Ehsan Valian, Shahram Mohanna and Saeed Tavakoli have proposed an improved cuckoo algorithm to enhance the accuracy and convergence rate of this algorithm. Cuckoo search algorithm has been used to solve various engineering design optimization problems and has provided better results as compared to other swarm intelligence techniques. In this work, design of a sixteen variable model of loudspeaker [1] has been optimized by using cuckoo search techniques. Rest of the paper is organized as follows:
An introduction to the loud speaker design problem is given in section II. Basics of Cuckoo search technique are given in section III. Loud speaker design optimization by using Cuckoo search is explained in section IV, followed by simulation results, conclusion and list of references.

II. Loud Speaker Design Optimization Problem

In this paper, loudspeaker design has been formulated as a 16 variables problem [1]. The design problem is to minimize the volume of material used in the construction of the loudspeaker. Sixteen design variables (x_1, x_2, x_3,…x_{16}) represent the dimensions of various parts as shown in Fig.1.

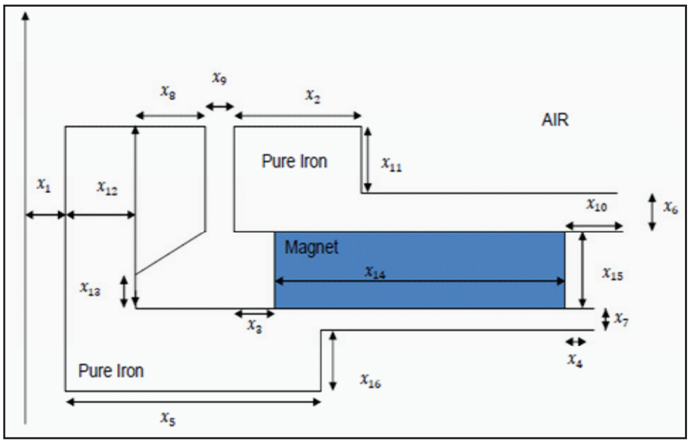

Fig. 1: Loudspeaker Design in Terms of 16 design variables [1]

The device must also present at least some minimum prescribed value for the magnetic flux density in the air gap in order to allow the loudspeaker to work properly. This condition has been modeled as an inequality constraint, in which the value of B is required to be larger than a given fixed value. So the proposed mathematical definition for the loudspeaker optimization problem is:

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Minimize f(d) = M(d)

Subjected to $B > B_0$,

Where f(d) is a part of the optimization function, which represents the volume of loudspeaker (dependent on dimensions of loudspeaker). Second part of the optimization function accounts for the the minimum prescribed value for the magnetic flux density in the air gap. Overall optimization function is given by eqn. 1.

$$F = M(d) + 100 \times \max(B_{Ref} - B) \quad (1)$$

The volume of material used in the loudspeaker is given by the solid generated by the revolution of the model around the central axis. The loudspeaker has been modelled [1] using the LUA scripting language [3] to describe the geometry of the device.

III. Basics of Cuckoo Search Algorithm [7]

Cuckoo search (CS) is an optimization algorithm developed by Xin-she Yang and Suash Deb [7] in 2009. It was inspired by the obligate brood parasitism of some cuckoo species by laying their eggs in the nests of other host birds (of other species).

Cuckoo species such as the New World brood-parasitic Tapera have evolved in such a way that some female parasitic cuckoos are often very specialized in the mimicry in colors and pattern of the eggs of a few chosen host species[7]. Parasitic cuckoos often choose a nest where the host bird just laid its own eggs. In general, the cuckoo eggs hatch slightly earlier than their host eggs. Once the first cuckoo chick is hatched, the first instinct action it will take is to evict the host eggs by blindly propelling the eggs out of the nest, which increases the cuckoo chick's share of food provided by its host bird.

Studies also show that a cuckoo chick can also mimic the call of host chicks to gain access to more feeding opportunity. Each egg in a nest represents a solution, and a cuckoo egg represents a new solution. The aim is to employ the new and potentially better solutions (cuckoos) to replace not-so-good solutions in the nests.

The flowchart of Cuckoo Optimization Algorithm (COA), as given in fig. 2 is self explanatory and essentially hasthree components: selection of the best, exploitation by local random walk, and exploration by randomization via levy flights . Use of this algorithm is beneficial as it involves less number of parameters. Moreover, it is more generic and robust for many optimization problems, when compared with other metaheuristic algorithms.

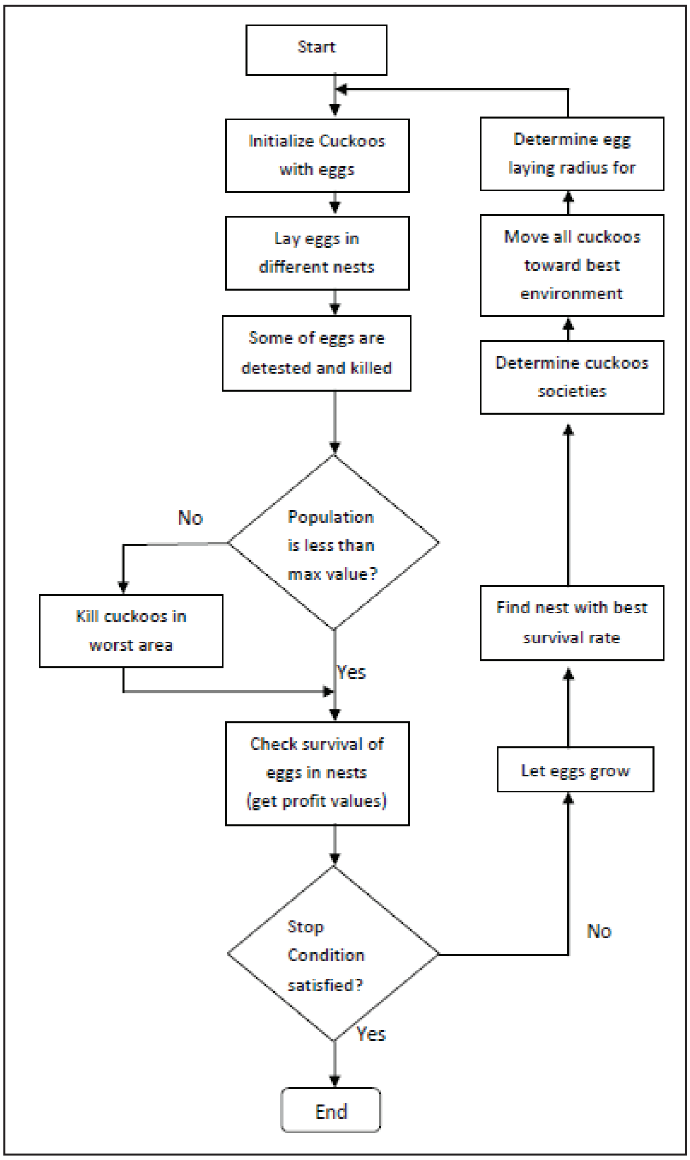

Fig. 2: Flowchart of Cuckoo Optimization Algorithm [7].

IV. Simulation Results

Loudspeaker design problem has been formulated as problem of optimizing the values of 16 design variables $((x_1, x_2, x_3,\ldots,x_{16})$ (each representing its dimension)), which result in minimizing the overall volume of the loudspeaker while maintaining a minimum flux density of 0.5 T. Minimum and maximum bounds of the design variables have been decided as per reference [1]. MATLAB is adopted as computer language which is used on a i-3 processor running at 2.50 GHZ with 2 GB of RAM. The loudspeaker has been modelled using the LUA scripting language to describe the geometry of the devices, and the Finite Element Method Magnetics 4.0 (FEMM) [4] software has been used to solve the magnetic problem. While using cuckoo optimization algorithm to solve this problem, the options used are as follows:

a) Number of nests = 25.
b) Discovery rate of alien eggs/solutions = 0.25.
c) No of iteration = 60.

Optimum values of 16 design variables, obtained by using Cuckoo search algorithm are given in Table 1.

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Table 1: Optimal Value of x using COA

Variable	Value (in mm)
X_1	3
X_2	1.07939193258009
X_3	1
X_4	1.00645556845366
X_5	5
X_6	2
X_7	1.07023527981883
X_8	1
X_9	0.513493358322725
X_{10}	0.0886407476285513
X_{11}	1.02535165821731
X_{12}	2.07117986593401
X_{13}	1.93966485560607
X_{14}	5.21502683361233
X_{15}	5
X_{16}	1.00040221040058

The Objective function value obtained from COA is **3.85345663920921** and the optimized volume is 3853.45 mm^3. The optimal value of flux density as calculated using FEMM software is **0.5157T**. Thus, there is a considerable reduction in overall volume of the material used for loudspeaker design (as compared to reference [1]) using this technique. At the same time, the constraint on flux density value is also satisfied.

IV. Conclusion

Simulation results show the potential of Cuckoo optimization algorithm to get a high quality solution to nonlinear, multi-modal as well as constrained problem (such as loud speaker design optimization) in electromagnetic domain, even under a small computational budget.

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