Preliminary Results of the Generalized Extremal Optimization Algorithm Applied in the Design of Optical Systems

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Abstract: The purpose of this paper is to present some preliminary results of the Generalized Extremal Optimization algorithm (GEO) applied to the problem of optical systems design. Two versions of GEO were used in the design of an air spaced triplet lens system, and their results compared to the ones obtained with a hybrid Genetic Algorithm.

OCIS codes: (080.0080) Geometric optics; (080.3620) Lens system design (080.2720) Mathematical methods.

1. Introduction

Since the 90's, evolutionary algorithms (EA) have been proposed for the optimization of optical systems with the objective of finding the global optimum for such systems. These kinds of optimization algorithms are attractive options to deal with the problem due to the fact that the search space in optical design is typically very complex, and it includes: several local minimums, high-dimensionality, strong epistasis, non-linearities, and non-continuous variables (i.e. optical glasses) [1-4].

Several different kinds of evolutionary algorithms with different variations have been reported with good results in the optical design problem, as: Genetic Algorithms (GA) [3-9]. Evolutionary Strategy (ES) [1-3] and Genetic Programming (GP) [9-11].

In this work we report preliminary results of the use of a relatively new evolutionary algorithm in the problem called Generalized Extremal Optimization (GEO).

2. The Generalized Extremal Optimization algorithm

The GEO in its canonical version was presented by De Sousa *et al*. (2003) [12], as a generalization of the Extremal Optimization (EO) algorithm, both based on the simplified evolutionary model of Bak-Sneppen [13]. The codification of the variables in GEO is binary as in GA, but it has the advantage of having only one free parameter to adjust called τ and its implementation is very simple. The detailed description of GEO can be found in [12].

In the last few years, variations of the canonical GEO have been suggested [14-15]. Lopes *et al.* (2008) [15], presented two variations of GEO using real codifications of the variables; GEO_{real1} and GEO_{real2}, showing better performances for some test functions than those of the canonical versions.

The GEO_{real2} has the same basic principle of GEO, but as it uses real codification, the changes made in the variable numerical values are very similar to the perturbations used in the ES. However, these changes in the algorithm resulted in other two free parameters, σ_1 and P. The detailed description of GEO_{real2} can be found in [15].

3. Test problem

To study the GEO performance in the optical design problem, we used one of the test problems proposed by Moore (1999) [6]. The problem is to design an f=100mm F/5 FOV=± 20° all spherical triplet lens corrected in the visible. The glasses are fixed during the optimization, and there are constraints of the minimum glass and air center, and edge spacing (≥4mm), and a maximum glass center thickness of 15mm.

4. Numerical implementation

The two GEO versions mentioned above, canonical GEO and GEO_{real2}, were implemented in MATLAB. Using a free MATLAB toolbox MZDDE, we were able to call the optical design software ZEMAX to trace rays as well as to calculate and return the merit function value. The merit function defined in ZEMAX was a default RMS spot with the added constraints . The weights used for constraints were 100 to avoid unfeasible solutions.

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For the canonical GEO, we tested different values of τ from 0.25 to 2 with a 0.25 increment. For the $GEO_{real2,}$ as it has three adjustable parameters (τ , P e σ_1), we limited ourselves to testing the best sets found for the test functions in [15]. The idea was to get some insight of which test function would have its design space closer to our problem.

5. Results

Fig. 1 and Fig. 2 show the layout and spot diagram for the best optical systems found by GEO and GEO_{real2} respectively, for all the executions of the algorithms. Each algorithm was executed 20 times with a stop criteria of 10^5 merit function calculation. For confrontation purposes, Fig 3 shows the optical system achieved in [6] using a hybrid GA.

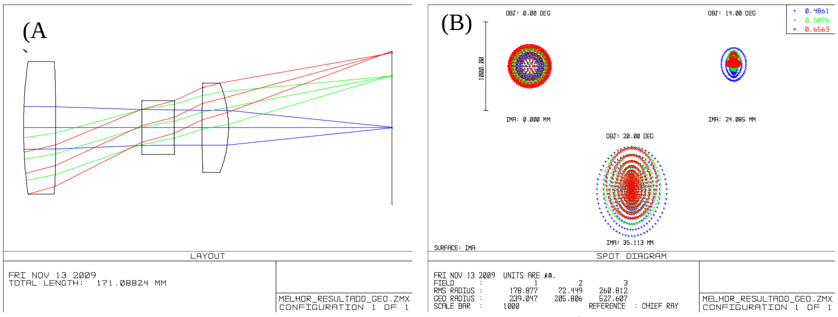

Fig. 1-(A) Best GEO optical system Layout. (B) Spot diagram for the best GEO system.

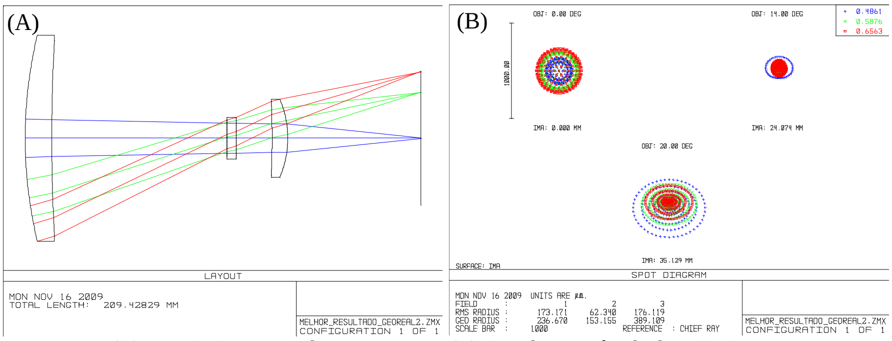

Fig. 2-(A) Best GEO_{real2} optical system Layout. (B) Spot diagram for the best GEO_{real2} system.

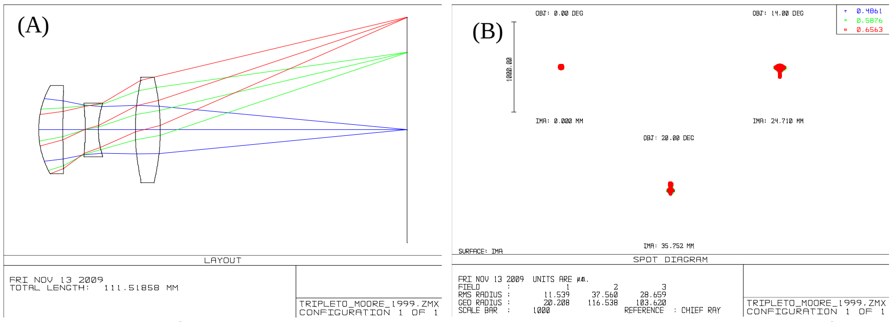

Fig 3- (A) Best triplet optical system found by Moore's (1999) hybrid optimization algorithm [2]. (B)Spot Diagram for the Moore's system.

The merit function value for the best GEO result (Figure 1) is 0.4234, which has accrued to $\tau = 1.75$. For the GEO_{real2}, the best merit function for the optical system (Figure2), as reported by its spot diagram, is a little better, 0.3442. This result was reached using $\tau = 2.25, \sigma_1 = 8, P = 8$.

In spite of the fact that GEO and GEO_{real2} didn't show great differences for the best merit function values found, we observed a great difference between the best average values for 20 independent executions of the algorithms. The best average result found with GEO is 9.194 for $\tau = 1$. On the other hand, for $GEO_{real2,}$ this value is 0.736 for $\tau = 2.25, \sigma_1 = 8, P = 8$.

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In spite of working, neither GEO nor GEO_{real2} presented results compatible with the [6] results, shown in Fig.3. The merit function value for this system is extremely low, 0.0628, and its impact on the image quality can be noticed by the system spot diagram.

A possible explanation for this performance discrepancy lies in the fact that the algorithm used in [6] is not a pure evolutionary algorithm, but a hybrid one, which uses GA for the exploration and a Dumped Least Square for exploitation. Nevertheless the system presented in [6] can be interpreted as a “global optimum” for the problem.

6. Conclusions

The published papers show that different evolutionary optimization algorithms have been studied and applied to optical design problems. In this work we present the results of GEO application to the problem, which has never been tested before. So far, however, neither of the GEO tested versions has presented results close to the one presented in [6] for the tested problem. Notwithstanding, this study is far from the end. A systematic tuning study for the free parameters in GEO_{rea2} can be conducted, other investigations about the algorithm performance can be carried out to better understand the weakness of the algorithm in the problem, different versions of GEO can be tested including a hybrid one, etc. A better understanding of GEO behavior in the specific problem of optical systems design, might allow method customizations for better performances. Also, other EA not yet tested in this kind of problem can be investigated.

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NOTE: The same results presented herein were also presented in an expanded Portuguese paper version during the 2010 internal workshop of the Space Engineering and Technology graduate course at the National Institute for Space Research in Brazil.