Automated Re-Invention of Six Patented Optical Lens Systems using Genetic Programming

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ABSTRACT

This paper describes how genetic programming was used as an invention machine to automatically synthesize complete designs for six optical lens systems that duplicated the functionality of previously patented lens systems. The automatic synthesis was done "from scratch"—that is, without starting from a pre-existing good design and without pre-specifying the number of lenses, the physical layout of the lenses, the numerical parameters of the lenses, or the non-numerical parameters of the lenses. One of the six genetically evolved lens systems infringed a previously issued patent; three contained many of the essential features of the patents, without infringing; and the others were non-infringing novel designs that duplicated (or improved upon) the performance specifications contained in the patents. One of the six patents was issued in the 21st-century. The six designs were created in a substantially similar and routine way, suggesting that the approach used may have widespread utility. The genetically evolved designs are instances of human-competitive results produced by genetic programming in the field of optical design.

Categories and Subject Descriptors

G.1.6–Global Optimization; I.2.2–Automatic Programming Program Synthesis; I.2.8–Control Methods and Search; J.2–Physics

General Terms

Design, algorithms

Keywords

Genetic programming, automated design, optical lens system, patents, human-competitive results, invention machine

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1 INTRODUCTION

An optical lens system is an arrangement of refractive or reflective materials that manipulate light [15].

Optical design is more of an art than a science. As Warren J. Smith states in *Modern Optical Engineering* [15, page 393]:

> "There is no 'direct' method of optical design for original systems; that is, there is no sure procedure that will lead (without foreknowledge) from a set of performance specifications to a suitable design."

An existing design is frequently the starting point of optical design by humans and by conventional optical optimization software. Accordingly, Smith [15] and others in the field have compiled thousands of historically important and useful designs (many previously patented) as starting points.

A complete design for a classical optical lens system encompasses numerous decisions, including the choice of the system's topology (that is, the number of lenses and their physical layout), choices for numerical parameters, and choices for non-numerical parameters.

The layout decisions required to define a lens system include the sequential arrangement of lenses between the object and the image, decisions as to whether consecutive lenses touch or are separated by air, the nature of the mathematical expressions defining the curvature of each lens surface (traditionally spherical, but nowadays often aspherical), and the locations and sizes of the field and aperture stops that determine the field of view and the maximum illumination of the image, respectively.

The numerical choices include the thickness of each lens and the separation (if any) between lens surfaces, the numerical coefficients for the mathematical expressions defining the curvature of each surface (which, in turn, implies whether each is concave, convex, or flat), and the aperture (semi-diameter) of each surface.

The non-numerical choices include the type of glass (or other material) for each lens. Each type of glass has various properties of interest to optical designers, notably including the index of refraction, n (which varies by wavelength); the Abbe number, V; and the cost. Choices of glass are typically drawn from a standard glass catalog.

This paper describes how genetic programming can be used to automatically create a complete design for an optical lens