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Potential of support vector regression for optimization of lens system

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HIGHLIGHTS

- Lens system design represents a crucial factor for good image quality.
- Optimization procedure is the main part of the lens system design methodology.
- Soft computing methodologies optimization application.
- Adaptive neuro-fuzzy inference system (ANFIS) application.
- Support vector regression (SVR application).

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ABSTRACT

Lens system design is an important factor in image quality. The main aspect of the lens system design methodology is the optimization procedure. Since optimization is a complex, non-linear task, soft computing optimization algorithms can be used. There are many tools that can be employed to measure optical performance, but the spot diagram is the most useful. The spot diagram gives an indication of the image of a point object. In this paper, the spot size radius is considered an optimization criterion. Intelligent soft computing scheme Support Vector Regression (SVR) is implemented. In this study, the polynomial and radial basis functions (RBF) are applied as the SVR kernel function to estimate the optimal lens system parameters. The performance of the proposed estimators is confirmed with the simulation results. The SVR results are then compared with other soft computing techniques. According to the results, a greater improvement in estimation accuracy can be achieved through the SVR with polynomial basis function compared to other soft computing methodologies. The SVR coefficient of determination R^2 with the polynomial function was 0.9975 and with the radial basis function the R^2 was 0.964. The new optimization methods benefit from the soft computing capabilities of global optimization and multi-objective optimization rather than choosing a starting point by trial and error and combining multiple criteria into a single criterion in conventional lens design techniques.

1. Introduction

Lens system design is a complex engineering task in analytical approaches [1,2] due to strong interactions among parameters and many local optima. There are also several design criteria, such as Seidel aberrations, chromatic aberrations, size and cost [3,4].

Lens system design mainly comprises two steps: calculating the initial lens and further optimization. The optimization method presents better and more robust results than the initial design [5,6]. Optimization is very important to lens system design [7]. For decades, various optimization methods have been successfully used in lens system design [8,9]. Optimization of a lens system involves determining the surface parameters defining the shape and position of each lens surface [10]. The mathematical model for this problem is generally complicated [11,12].

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The goal of the optimization process is to find the minimum merit function in a multi-dimensional variable space [13–16]. In each step of the optimization procedure, the search direction in terms of optimization variables has to be found [17–19]. The cycle continues until the merit function is sufficiently small.

Traditional methods of optimization can be effectively employed on continuous and differential functions. But many complex real world engineering problems involve efficiently solving problems in areas of structural optimization, design and analysis of control systems and scheduling. These disciplines are characterized by nonlinear, multi objective dynamical systems that face major obstacles of getting stuck in non-optimal solutions and premature convergence [20].

Even though a number of mathematical functions have been proposed for optimization of the lens system geometrical parameters, there are still disadvantages of the models like very demanding in terms of calculation time. Meta heuristics are a class of powerful stochastic algorithms, which have been proved over the years as efficient and fast problem solvers [21–23]. Computational intelligence (CI) belongs to this class of Meta heuristic search techniques. CI is an emerging derivative of artificial intelligence and has recently gained attention from varied fields of science, technology and management since it is an established metaheuristic optimization technique [24]. Artificial neural networks (ANN) can be used as alternative to analytical approach as ANN offers advantages such as no required knowledge of internal system parameters, compact solution for multi-variable problems and fact calculation. For optimization of complex systems, new techniques can be used, such as the fuzzy logic (FL) [25], ANN [26] and neuro-fuzzy [27].

Support vector machines (SVMs) as on type of metaheuristic soft computing technique, have gained importance regarding issues related with the environment [28,29]. There are two fundamental classes of support vector machines: support vector classification (SVC) and support vector regression (SVR). SVM is a learning framework utilizing a high-dimensional peculiarity space [30–33]. SVR is focused around a measurable learning hypothesis and structural risk minimization rule and has been effectively utilized for nonlinear frameworks [34,35]. The correctness of an SVM model is to a great extent reliant on determining the model parameters. Notwithstanding, organized strategies for selecting parameters are important. Hence, model parameter alignment ought to be made.

SVR with radial basis function and SVR with polynomial basis function are used to determine lens system geometric parameters. Besides, the adaptive neuro fuzzy (ANFIS) model and improved versions of ANFIS, like ANFIS-PSO (ANFIS-particle swarm optimization) [36–38], ANFIS-GA (ANFIS-genetic algorithm) [39,40], and ANFIS-ACO (ANFIS-ant colony optimization) [41–43], are also investigated for comparison.

The main task is to investigate and compare the soft computing methods for the estimation of the optimal geometrical parameters of a lens system. Until now there are no reports of using of SVR approach for optimization of the lens system geometrical parameters. Several soft computing techniques are used to illustrate the capabilities of each method. As a measure of optimal functionality of the lens system, spot size radius of the lens system is minimized to achieve best image quality. The soft computing networks attempt to reduce the aberration and distortion in the lens system. Finally, the optimal result will present the optimal image quality of the lens system.

2. Materials and methods

2.1. Lens design problem

In this article, a doublet lens system was used for the analysis of optimization techniques. Fig. 1 shows the doublet lens system as an example for the optimization procedure in this work.

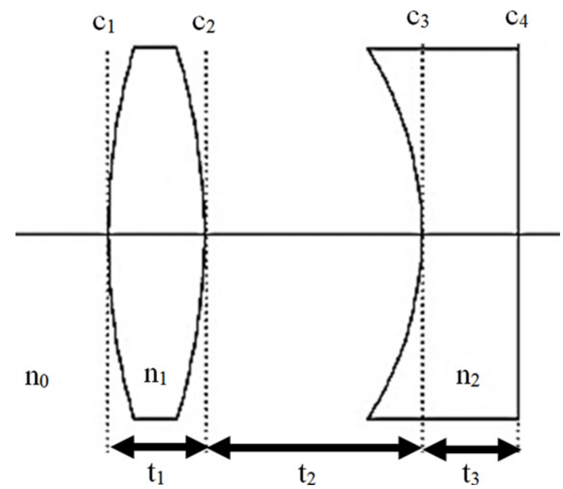

Fig. 1. The main parameters of the lens system: n_i—refractive index, c_i—lens surface curvature, t_1 and t_3—lens thicknesses, and t_2—lens spacing.

Designing the doublet lens system involves selecting the overall power $\emptyset_{sys}$ of the doublet with the two glass lenses to be used. The glass choice gives the Abbe number V. For the linear dispersion of the system to become zero the system has to satisfy the following equations:

$$\emptyset_1 + \emptyset_2 = \emptyset_{sys} \tag{1}$$

$$\frac{\emptyset_1}{V_1} + \frac{\emptyset_2}{V_2} = 0 \tag{2}$$

where the lens power is $\emptyset = \frac{1}{f}$ for a lens with focal length f. From Eqs. (1) and (2) we can get:

$$\frac{\emptyset_1}{\emptyset_{sys}} = \frac{V_1}{V_1 - V_2} \tag{3}$$

$$\frac{\emptyset_2}{\emptyset_{sys}} = \frac{-V_2}{V_1 - V_2}. \tag{4}$$

Since $\emptyset_2 = -\emptyset_1 \frac{-V_2}{V_1}$ and the Abbe numbers are positive, the power of the second element in the doublet system would be negative when the first element is positive.

To characterize lens systems, ray tracing is required. Beginning at a given point on the item and a given starting plot, a ray is the processing of the trajectory through the optical framework until it achieves the picture plane. Fig. 2 shows the layout of one lens system with some of the ray paths. There are numerous parameters that a lens creator must focus on to get a lens with excellent picture framing abilities: the shape of the surfaces, the thickness between two surfaces, material of the lens components, the quantity of lens components, and so forth. Image blur and distortion at a certain wavelength can be improved by changing the curvature of surfaces and thickness between surfaces.

In this paper, the aim is to examine the curvature of surfaces, c_i, and thickness between two surfaces, t_i, to obtain a lens with good image-forming capabilities (Fig. 2). D_{pupil} is the diameter of the bundle of rays with an entrance angle of zero degrees. The curvature (radius) of all surfaces and the distance from it to the image surface are modified to meet a required spot size radius of the lens system. The lens system is investigated by using spot diagrams made by performing ray tracing. 22 input rays with input angles varying from 0 to 22° are used. The grid at the aperture stop (or at the entrance pupil) traces the rays from the object that pass through all grid points. At the image plane, the collection of intersection points creates a spot diagram (Fig. 3). The post diagram sizes could serve as an image quality indicator.