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Adaptive neuro-fuzzy estimation of optimal lens system parameters

Dalibor Petković [a], Nenad T Pavlović [a], Shahaboddin Shamshirband [b,*], Miss Laiha Mat Kiah [b], Nor Badrul Anuar [b], Mohd Yamani Idna Idris [b]

[a] University of Niš, Faculty of Mechanical Engineering, Deparment for Mechatronics and Control, Aleksandra Medvedeva 14, 18000 Niš, Serbia
[b] Department of Computer System and Technology, Faculty of Computer Science and Information Technology, University of Malaya, Kuala Lumpur, Malaysia

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ABSTRACT

Due to the popularization of digital technology, the demand for high-quality digital products has become critical. The quantitative assessment of image quality is an important consideration in any type of imaging system. Therefore, developing a design that combines the requirements of good image quality is desirable. Lens system design represents a crucial factor for good image quality. Optimization procedure is the main part of the lens system design methodology. Lens system optimization is a complex non-linear optimization task, often with intricate physical constraints, for which there is no analytical solutions. Therefore lens system design provides ideal problems for intelligent optimization algorithms. There are many tools which can be used to measure optical performance. One very useful tool is the spot diagram. The spot diagram gives an indication of the image of a point object. In this paper, one optimization criterion for lens system, the spot size radius, is considered. This paper presents new lens optimization methods based on adaptive neuro-fuzzy inference strategy (ANFIS). This intelligent estimator is implemented using Matlab/Simulink and the performances are investigated.

1. Introduction

Optical lenses are increasingly being recognized as very important parts of high-value added products with the continuous growth of the optical information technology market. Lens system design is a complex engineering task that cannot be achieved by an analytical approach [1,2]. This is because the lens design problem has many parameters to be determined, strong interactions among parameters and many local optima, and also because it has many criteria such as well-known Seidel aberration, chromatic aberration, size and cost [3,4].

The design of the lens system 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 determination of the surface parameters defining the shape and position of each lens surface [10]. The mathematical model for this problem is generally complicated [11,12].

The goal of the optimization process is to find the minimum of the merit function in a multi-dimensional variable space [13]. In each step of the optimization procedure, the search direction in terms of the optimization variables has to be found [14]. The cycle will continue until the merit function is small enough.

Three types of approach are available for improvement of lens performance:

1. Design to meet a theoretical minimum condition [15,16].
2. Correction of one or more defects of the lens by additional components [17].
3. Optimization by variation of parameters from an initial configuration. A target function is defined, possibly as a numerical combination of the quantities of interest. This function is evaluated for successive sets of chosen parameters. The values of these parameters are varied with the aim of minimizing the target function. Constraints may be required on values of any of the parameters, or on functions of them or of the target function [18–20].

The traditional methods of optimization techniques can be effectively employed on continuous and differential functions. But many complex real world engineering problems involve to efficiently solving problems in areas of structural optimization, design and analysis of control system and scheduling problems. These disciplines are characterized by nonlinear, multi objective dynamical systems which are faced with major obstacle of getting stuck in non-optimal solution and premature convergence [21,22]. Meta heuristics are a class of powerful stochastic algorithms which have been proved over the years as an efficient and fast problem solver

* Corresponding author. Tel.: +60146266763.
E-mail addresses: dalibortc@gmail.com (D. Petković), shahab1396@gmail.com (S. Shamshirband).

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of such magnitude [23–25]. Computational intelligence (CI) belongs to this class of Meta heuristic search technique [26–28]. CI is an emerging derivative of artificial intelligence which has recently gained attention from varied fields of science, technology and management since it is an established Meta heuristic optimization technique [29]. Aiming at optimizing such complex systems to ensure optimal functioning of the unit, new techniques are used today such as the fuzzy logic (FL) [30,31], artificial neural network (ANN) [32] and neuro-fuzzy [33].

ANNs are flexible modeling tools with capabilities of learning the mathematical mapping between input and output variables of nonlinear systems. One of the most powerful types of neural network system is adaptive neuro-fuzzy inference system ANFIS [34]. ANFIS shows very good learning and prediction capabilities, which makes it an efficient tool to deal with encountered uncertainties in any system. ANFIS, as a hybrid intelligent system that enhances the ability to automatically learn and adapt, was used by researchers in various engineering systems [35–41]. So far, there are many studies of the application of ANFIS for estimation and real-time identification of many different systems [42–50].

The key goal of this investigation is to establish an ANFIS for estimation of the optimal geometrical parameters of the lens system. 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 ANFIS network attempts to reduce the aberration and distortion in the lens design. The optimal result, where the total blur size is reduced, generally will indicate the optimal image quality.

The basic idea behind the soft computing methodology is to collect input/output data pairs and to learn the proposed network from these data. The ANFIS is one of the methods to organize the fuzzy inference system with given input/output data pairs [51,52]. This technique gives fuzzy logic the capability to adapt the membership function parameters that best allow the associated fuzzy inference system to track the given input/output data.

ZEMAX in sequential mode was used to simulate the lens system. The used glass material was BK7. Afterward, the ZEMAX was used for optimizing of the lens system. The optimized results is then extracted and used as training data for the proposed ANIFS system. The purpose of this study is to set up an optimal design system for lens system development. The optimization system is proposed to develop the geometric shape of the lens.

1.1. Defining lens design problem

A lens system is an arrangement of lenses with specific refractive indices, surface curvatures, thicknesses and spacing [53,54]. Fig. 1 shows an example of a two-lens sequential system

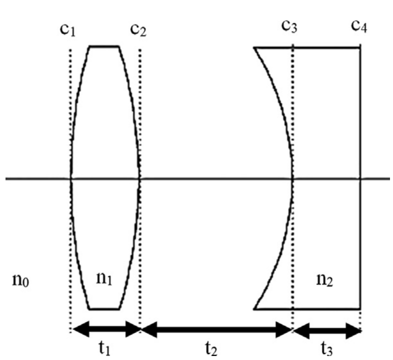

Fig. 1. Parameters of a two-lens system: n_i represents the refractive index of a media, c_i is a lens surface curvature, t_1 and t_3 are the lens thicknesses, and t_2 is the lens spacing.

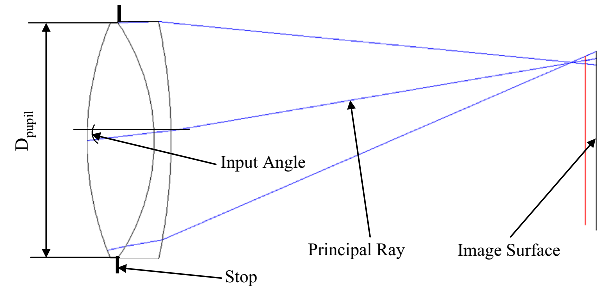

Fig. 2. An example of the lens sequential doublet system.

(doublet lens system). Given an object of specific size at a certain distance, its function is to produce an image of this object.

To characterize lens systems, ray tracing is needed. Starting at a given point on the object and a given initial angle, a ray trace is the computation of the trajectory of a light ray through the optical system until it reaches the image plane. Fig. 2 shows the layout of one lens system, showing some of the ray paths through the lens. The object is located a long distance to the left. The bundles of rays from each object point enter the lens as parallel bundles of rays. Each ray bundle passes through the lens and is focused toward an image point on the image surface. There are many parameters that a lens designer must determine to get a lens with good image forming capabilities; the curvature of surfaces, thickness between two surfaces, materials of lens element, the number of lens elements, etc. We can improve the blur and the distortion of an image in a certain wavelength by changing the curvature of surfaces and thickness between surfaces because we can control the refraction of rays with one wavelength at each surface by doing them. By increasing the number of lens, we can get a lens with better performance because the degree of freedom of the lens system increases. However, it becomes difficult to optimize the lens, and the size and the cost of the lens increase.

In this paper, we consider to search the curvature of surfaces, c_i, and thickness between two surfaces, t_i, to obtain a lens that has good image forming capabilities (Fig. 2). D_{pupil} is the diameter of the bundle of rays with the entrance angle of zero degree. To make the problem simple, the indices of refraction of each lens element are fixed in this paper, which means that we do not consider the chromatic aberration. The number of the surfaces, N, are also fixed as in most of other lens optimization methods. The curvature (radius) of the all surfaces and the distance of it to the image surface are modified to meet a required spot size radius of the lens system. The lens doublet system is evaluated by using spot diagrams made by performing ray tracing. In ray tracing, the 22 bundles of rays whose entrance angle varies from 0° to 22° are used. Each bundle of rays consists of a principal ray and other ten rays surrounding and parallel to the principal ray. 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 collection of intersection points creates spot diagram (Fig. 3). The post diagram sizes could be used as image quality indicator.

1.2. Design parameters

Lens design programs are called sequential ray traces because they trace geometrical rays through an optical system in a predefined sequence. The following information needs to be available to the optical design of the lens system before a system can be analyzed:

1. System aperture type and size,
2. Surface information,
3. Number of surfaces,