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Optical design of contact lenses using principal component analysis method with Taguchi method ☆

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ABSTRACT

In this study, an optimal contact lens design for myopia and astigmatism eyes was proposed. In addition to the optical parameters of the human eye, the physiologically relevant parameters of design have become the subject of increased focus. If we compacting overall volume size, the value of spherical aberration (SA) at wide radius of contact lens seems lower. If we corrected the design to improve the value of SA, modulation transfer function (MTF) and coma aberration (TCO) value would become lower relatively. Hence we integrated the optimal method of Taguchi method and mathematical analysis scheme of principal component analysis (PCA) to optimize the multiple quality characteristics (SA, TCO and MTF) of the contact lens. By combining Taguchi and PCA methods, a set of optimum design parameters was well selected to balance the values of SA, TCO and MTF that improve the SA 25.63%, TCO 91.88% and MTF 2.4% than commercial optical design software of CODE V.

1. Introduction

The optical design of contact lenses and glasses has received extensive attention. Due to the eye naturally occurring aberration phenomenon, curvature of the eye is not the spherical diameter equidistant, careful observation of the cornea and the lens curvature of the eye of the more prominent eye central, surrounded by relatively flat, this way, the light entering the eye elapsed since the refraction angle of refraction, will be showing a certain degree of aberration [1].

This study should assist optical designers in further optimizing contact lens (myopia is 550° and astigmatism is 175°) after normal optimization by current optical software, in order to achieve its theoretical maximum performance. The Taguchi method for the design parameters [2] of the contact lens is introduced to efficiently eliminate third-order aberrations, such as spherical aberration [3–5].

The research presents that Taguchi method has been successfully developed to optimize and analyze design processes with static and dynamic characteristics [6,7]. But the conventional Taguchi method can only be applied to a single performance quality characteristic [8]. Hence, the principal component analysis (PCA), a useful statistical technique, was applied to examine the relationships between a given data set of multiple performance characteristics (MPC) to improve the

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performance of the system. With the aid of PCA, the principal components and their explanatory power could be further integrated as a single quality characteristic for the MPC optimization of the lens [9,10].

The section list of this study as following: At Section 2, the methodology of optical design for the contact lens is presented. Section 3, is presented theory and formulas. Section 4 shows conclusions.

2. Methodology of optical design for contact lens

There are four steps for our proposed optimization algorithm of contact lens. First, the design specifications should be given in accordance with the design requirements. Next, in compliance with the design specifications, Liou & Brennan eye model [11] was constructed by the optical emulation software CODE V. Third, we optimized the lens design by applying the necessary restrictive conditions. Finally, the initial design of the contact lens was completed. The initial design specifications are given in Table 1. The aspheric surfaces are employed in front and rear lens [12]. The contact lens layout is presented in Fig. 1. After using CODE V built-in optimal technologies, the values of third-order aberrations are as shown in Table 2.

3. The optimization algorithm of Taguchi method

The Taguchi and the PCA methods were employed to optimize the performances of the contact lens. The Taguchi method is a powerful experimental design tool developed by Taguchi and Konishi [13] for solving the engineering problems of optimizing the performance, quality and cost of a product or process in a simpler, more efficient and systematic manner than traditional trial-and-error processes.

Orthogonal array of Taguchi method uses to execute experiments and to analyse results for each control factors. Orthogonal arrays consist of inner and outer columns, with the former designated the control factors while the latter is named the noise factors. In general, the performance of the contact lens is governed by five control factors, each with three level settings. Accordingly, the Taguchi trials were configured in an L18 orthogonal array. The control factors and three levels are listed in Table 3.

The quality of the design solution obtained from each run in the orthogonal array is evaluated using a signal-to-noise (S/N) ratio. Depending on the experimental objective, different quality characteristics may be pertinent. In the Taguchi methodology, the quality of any particular design solution is quantified using a ratio. The form of this ratio depends on the particular aspect of the product or process being optimized, and can be generalized as either "nominal is best," "smaller is better," or "larger is better" [14].

In the current Taguchi experiments, the objective is to reduce the spherical aberration and coma aberration. Consequently, the success of any factorial combination in reducing the spherical aberration and coma aberration is evaluated using the smaller-the-better ratio. But the Modulation Transfer Function (MTF) is evaluated by using the larger is better ratio.

$$\text{Smaller the better}: SN_i = -10\log\left(\sum_{i=1}^{N_i}\frac{y_i^2}{N_i}\right), \tag{1}$$

$$\text{Larger the better}: SN_i = -10\log\left(\frac{1}{N_i}\sum_{i=1}^{N_i}\frac{1}{y_i^2}\right). \tag{2}$$

4. The optimal parameter design of multiple quality characteristics with PCA

In practical applications, the products are considered to have many qualities. Usually one aspect is improved and another is not. Therefore, all qualities would normally be expected to seek a balance. In the traditional Taguchi experimental design method, only one quality characteristic could be considered. More than one correlated quality characteristic is usually considered in a lens design product. PCA is an effective means of determining a small number of constructs, which account for the main sources of variation in such a set of correlated quality characteristics [15].

Table 1
The initial design specifications of contact lens.

Initial conditions of design	
The radius of contact lens	8.6 [mm]
The thickness of contact lens	0.04 [mm]
The index of refraction	1.489
The semi-aperture of contact lens	7.3 [mm]
The coefficient for the quadratic surface	0

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