EPJ Web of Conferences **335**, 02010 (2025) https://doi.org/10.1051/epjconf/202533502010
EOSAM 2025

Global Optimization of Freeform Design Using Simple Saddle Point Detection

Kumar Rishav[1*] and *Florian* Bociort[1]

[1]Imaging Physics, Applied Sciences, TU Delft, 2628 CJ Delft, Netherlands

Abstract. Global optimization in optical design is particularly challenging for aspheric and freeform surfaces due to their complex, non-symmetric nature and the presence of numerous local minima in high-dimensional design spaces. Traditional optimization methods often struggle to efficiently escape these local minima, leading to suboptimal solutions. To address this, we propose the Simple Saddle Point Detection (SSPD) Algorithm, which enhances optimization by systematically identifying transition points that connect different design regions. By leveraging these pathways, the algorithm enables a more structured exploration of the design space, improving the convergence toward high-performance solutions. This study applies the SSPD approach to optimize complex optical systems, including catadioptric and multiple (folded) imaging mirror systems, where conventional methods face significant limitations. The results demonstrate that this approach is highly effective in refining aspheric and freeform optical designs, facilitating more efficient and reliable global optimization. Finally, we present the global search results as a closed network, highlighting the capability of SSPD to navigate complex design landscapes and achieve superior optical performance.

1 Introduction

Optical systems involve numerous parameters each influencing performance in a highly nonlinear way. A typical merit function [1] of an optical design is of the form:

$$\psi = \sum_{i=1}^{m} (\omega_i . f_i)^2 \qquad (1)$$

where i is the index for the sum over different parameters or surfaces (1 to m); ω_i is the weighting factor for the i-th parameter and f_i represents some optical performance metric or system specifications(such as wavefront error, focal length, etc.). Designing optical systems with aspheric and freeform surfaces involves optimizing numerous interrelated parameters, making the merit function a high-dimensional design space. As a result, the optimization landscape is complex, filled with multiple local minima and saddle points, which make finding the best possible design challenging. Current methods work well for refining existing

* Corresponding author: K.Rishav@tudelft.nl

designs but often get stuck in local minima, preventing the discovery of truly optimal solutions. One alternative is brute-force search, which systematically evaluates all possible parameter combinations. However, this is impractical because the number of possible designs grows exponentially with the number of variables, making an exhaustive search computationally infeasible. To address this, we present the SSPD method that leverages saddle point detection to navigate the optical design landscape more efficiently. This approach combines the mathematical properties of saddle points with an understanding of how the degrees of freedom (DOF) in optical systems can be manipulated to transition from one local minimum to another. Building upon the findings of Bociort et al. [2], the SSPD method capitalizes on the network-like structure of local minima in the optimization landscape. By systematically identifying and connecting these minima through saddle points, SSPD effectively navigates the design space, leading to enhanced convergence toward optimal solutions in optical system design. Unlike brute-force approaches, this method offers a structured way to navigate the high-dimensional design space while minimizing unnecessary computations.

2 Methodology

The objective of this method is to locate saddle points in the optimization landscape. The SSPD approach systematically explores the design space of aspheric and freeform optical systems by identifying key geometric features such as minima and saddle points (Fig. 1). By leveraging a global optimization framework, it efficiently navigates the complex parameter space to enhance system performance. This strategy emphasizes structured exploration, enabling better convergence toward optimal solutions while avoiding local traps. Additionally, the analysis provides insights into the merit function topology, facilitating informed design choices and improving optical system efficiency.

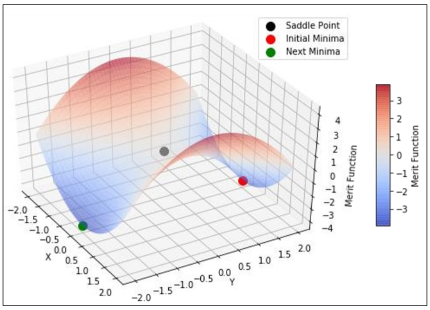

Fig. 1. The algorithm transitions from a local minimum to a saddle point, establishing a pathway to another local minimum.

3 Results and Discussions

We demonstrate the SSPD algorithm and present the results of the global optimization for a freeform design. Saddle points act as "bridges" connecting local minima, forming a network that facilitates transitions and uncovers better design solutions within the landscape. This method systematically explores the optimization landscape for saddle points, leveraging the handling of DOFs to identify all connected local minima and generate a network diagram.

References

1. K. Rishav, C. Reichert, A. Herkommer, Holistic Optimization of Optical Systems. Digit. Opt. Technol. 11062, 110620P (2019). https://doi.org/10.1117/12.2526413
2. Florian Bociort, Eco van Driel, Alexander Serebriakov, "Network structure of the set of local minima in optical system optimization," Proc. SPIE 5174, Novel Optical Systems Design and Optimization VI, (6 Nov 2003); https://doi.org/10.1117/12.504522