

GENETIC-ALGORITHM-BASED TWO-STAGE OPTIMIZATION FOR A FREEFORM PRISM AR OPTICAL SYSTEM

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Introduction. Near-eye AR displays often use a prism-like optical element to fold the optical path and keep the system compact. With freeform surfaces the field of view can be large, but the design space becomes wide and nonlinear. We build a two-stage GA workflow with fast ray tracing to obtain and refine an initial layout for a freeform-prism AR system. The work presents the results of the testing this procedure for FOV 35.35°, Eye box 3×3 mm.

Main part. A free-form prism AR system is a very flexible design that can provide a high image quality with proper optimization. Due to the large number of variables involved to optimization of the system the process is very unstable and need fine tuning with many trials. We considered using one of the global optimization algorithms – genetic algorithm (GA) to optimization of such system type, and a two-stage procedure to provide better stability of the optimization. Each surface in the system considered as described by the equation:

$$s(y, z) = \frac{r^2}{R[1 + \sqrt{1 - (1+K)r^2/R^2}]} + a_1y + a_2z + a_3y^2 + a_4yz + a_5z^2 - \text{an aspheric base term}$$

(with R - radius of the curvature, K - conic, r - radial height of the surface) plus low-order polynomial terms (with a_1, a_2, \dots, a_5 as - polynomial terms describing the higher order aspherical deformation).

Stage 1 (“pathfinder”) runs a single-objective GA over 16 geometric parameters while fixing freeform (polynomial) coefficients to zero. Fitness equals a status score (large when rays are lost early) plus a wedge penalty.

Stage 2 runs a multi-objective GA and optimizes the freeform terms on the surfaces (each coefficient within $\pm 5 \times 10^{-3}$). The best Stage-1 solution p_1 is copied 50 times to seed the initial population; each copy is perturbed by a small uniform noise of about $\pm 1\%$ (relative). From the Pareto set we pick one design by checking path feasibility first, then selecting the smallest center-field RMS spot radius while also checking the worst field and the image size target.

Results: We ran the full pipeline 50 times. Using the IQR rule (Interquartile Range Method), 7 runs were removed as outliers (n=43 kept). In the filtered set, the median center-field RMS spot radius is 0.056 mm (mean 0.059 mm) and the best run reaches 0.006 mm. The runtime per run is 23–76 s (median 39 s with AMD Ryzen 9 5950X 16-Core Processor). A 200-sample Monte-Carlo test shows that the z^2 coefficient on surface A is most often the dominant driver of RMS change.

Conclusion. The two-stage GA workflow can automatically produce a feasible freeform-prism layout and then improve it to good nominal image quality without manual tuning. Repeat-run statistics and IQR filtering describe typical performance, and the sensitivity ranking highlights the parameters that need tighter control in fabrication.

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