Automation of A Lens Design using the Genetic Algorithm

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In recent years, researches of the automation in a lens design have been actively carried out with improvement in a computer performance. But many of the researches are the techniques which are based on local search, and Damped Least Squares (DLS) is the most representative one.

The lens design is to determine an arrangement of lens with different refractive indexes, surface curvatures, and thickness. But the design process is heavily dependent on the experiences of the specialists. It is known that the lens design problem is very difficult task because there are many local optimum in the search space.

Ono et al. applied the Genetic Algorithm (GA) to that the lens design problem because it is excellent in a global optimization. And they succeeded in finding the lens systems which have been experientially thought to be the optimal and the semi-optimal solution in the three or four element lens design problem. In their optimization, the lens system are formalized with the curvatures of the surfaces and the distance between the surfaces. To make the problem simple the refraction indexes of glass were fixed, and the evaluation of the lens systems are done by the ray tracing with a single wavelength. Therefore their formalization did not consider the chromatic

aberration. This simplicity make the problem differ from an actual lens design.

We first use this simple evaluation method and compare the performance of the GA which Ono et al. used in their experiments with other GAs which are are recently proposed and show its efficacy on some benchmarks. Consequently, it was shown that we cannot say that the global search technique such as GA is not necessarily useful to optimize lens system, but the direction of the technique using local search is more suitable for this problem. Based on the results, we propose a new generation alternation model using the neighboring search and apply it to the lens design problem. And then we will show our proposed model work well better than the previously applied GA for the lens design problems. Moreover, this model have a feature that it can produce multiple solution candidates of the lens systems by a single trial. This is a big advantage of this technique because it is hopeful to obtain many solution candidate in a given specification of the lens system.

The new generation alternation model using the neighboring search proposed in this paper is the way that restricts the parents used for the crossover operator to K individuals that is similar to each other in a certain measure. This measure is basically defined by the Euclid distance measure on the genotype space. We finally propose the measure that is calculated by Euclid distance measure on the subspace that consist of the curvatures. Though this technique can avoid the useless searches of the global search by restricting the parents to the K neighbor individuals, there is a risk that some search domains cannot be searched. Then, we additionally propose a duplicate selection method. It permit the individuals to be selected for the parents beyond the neighboring individual. Employing this duplicate selection method with a certain rate, we can reduce the risk of the evolutionary stagnation.

In survival selection, the two individuals from a family are chosen, which we are left to the next generation is chosen from a family. The family here is the group of the parent individuals chosen by duplicate selection, and the child generated by the crossover operation. The family leaves the two individuals with the highest degree of adaptation to next generation, and replaces with two individuals chosen at random out of the parent

individuals chosen by duplicate selection.

The lens system are optimized using the new generation alternation model proposed above, and using the crossover operation. Though Ono et al. used the Unimodal Normal Distribution (UNDX) as the crossover operation, we use it and other two crossovers, UNDX-m and CPX, that are recently proposed. We treat lens design problem including three element and four element lens systems that are historically well studied. Consequently, in three element and four element lens design problems, we showed that our proposed method was able to obtain the optimal solution and the semi- optimal solution more efficiently than the standard GA used in previous experiments.

Moreover, we introduce the following three improvements into the evaluation of the lens system in order to take the chromatic aberration into consideration.

1. Introduction of the evaluation method corresponding to chromatic aberration

2. Generation of an achromatic lens

3. Automatic selection of glass

In the improvement 1, we employ multiple wavelength (d-wavelength, C-wavelength, F-wavelength), instead of the conventional one wavelength (only d-wavelength), that has been actually used in human lens design. And then the ray tracing of each wavelength are carried out, and the gap of the positions at which the corresponding rays intersect the image surface was evaluated to evaluate the chromatic aberration. The method of ray tracing perform to the wavelength In the improvements 2, we can treat achromatic lens which are often used to reduce the chromatic aberration in the actual lens design. For the improvements 3, we treat the refractive indexes and Abbe number as the control parameters. So we can introduce the chromatic aberration into the optimization of the lens systems by using above improvements. Those improvement was implemented and applied to the lens design problem. And it was shown that our proposed new generation alternation model can rectify the chromatic aberration efficiently.