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Optical Design at The Age of AI

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Abstract. Data-driven methods to assist lens design have recently begun to emerge; in particular, under the form of lens design extrapolation to find starting points (lenses and freeform reflective system). I proposed a trip over the years to better understand why the AI have been applied first to the starting point problems and where we are going in the future.

1 Introduction – Historical Perspective

Early in 80's, D. Dilworth presented his perspective on AI in lens design [1]. He talked about two primary approaches that have been taken at that time in his companie. The first was the 'natural-language interfacing' and the second was the use AI as an expert system. The first is far from our actual conception of AI but the second is somehow a means for the software to 'learn' about optics by studying lenses designed by expert to formulate rules. He recognised that AI was a what he called a 'virgin territory' because no one has investigated the potential of AI in lens design.

In the 90's, the trends in lens design were about global optimization and genetic algorithms [2,3,4]. Dilworth refined his 'expert system' which can be seen today as different as a AI application [5]. The idea of AI in lens design was not anymore on the radar.

At the IODC conference in 2002, Shannon did a talk about 'Fifty years of lens design; What do we know now that we did not know then?' [6]. I peak the following sentence from the manuscript: 'Progress in the future will likely require building more basic knowledge into design programs. Future lens design programs will need to incorporate learning and teaching function. Design programs should become a repository of knowledge as well as a set of tools.'. Shannon saw that design program can do more and more and this is maybe the future.

So the next decade, new applications come in the field, the first one was the computational imaging [7], follow by new type of surface including Zernike and freeform to name a few. These new lens design trends required additional skills that is not fully mastered by lens designer. Consequently to efficiently used it, lens designer need some helps. This is why (maybe) one of the first AI application was about freeform [8].

Over all those years, we can affirm that from a lens design point of view, the AI can be useful if it can:

- Accelerate the development process for optical system
- Enhance productivity of the deisgners
- Reduce costs.

In this presentation we will try to describe three applications that can beneficial from AI in lens design.

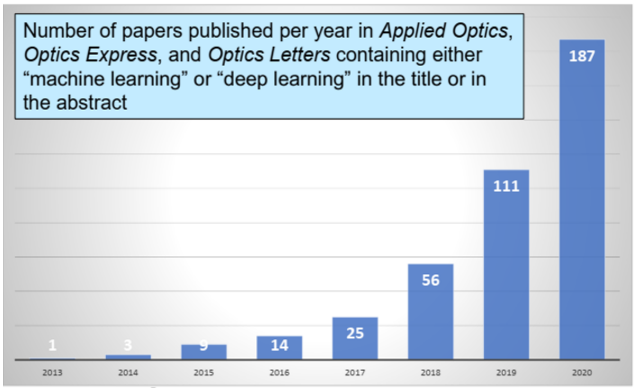

Fig. 1. Number of papers published per year in AI-Optics [9].

2 Few Applications

2.1. Starting Points

The first application is a simple, highly modular deep neural network (DNN) framework to address the problem of automatically inferring lens design starting points tailored to the desired specifications. In contrast to previous work, our model can handle various and complex lens structures suitable for real-world problems such as Cooke Triplets or Double Gauss lenses. Our successfully trained dynamic model can infer lens designs with realistic glass materials whose optical performance compares favorably to reference designs from the literature on 80 different lens structures. Using our trained model as a backbone, we make available to the community a web application that outputs a selection of varied, high-quality starting points directly from the

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desired specifications, which we believe will complement any lens designer's toolbox [10].

2.2 Diversity

The second example was to build a deep learning-enabled LDE framework with the aim of generating a significant variety of microscope objective lenses (MOLs) that are similar in structure to the reference MOLs, but with varied sequences [11]. As a particular arrangement of glass elements, air gaps, and aperture stop placement. We first formulate LDE as a one-to-many problem—specifically, generating varied lenses for any set of specifications and lens sequence. We then quantify the structure from the slopes of its marginal ray. From only 34 reference MOLs, we generate designs across 7432 lens sequences and show that the inferred designs accurately capture the structural diversity and performance of the dataset. Our contribution answers two current challenges of the LDE framework: incorporating a meaningful one-to-many mapping, and successfully extrapolating to lens sequences unseen in the dataset—a problem much harder than the one of extrapolating to new specifications.

2.3 Challenges using data-driven methods

Finally, as data driven approaches have proven very efficient in many vision tasks, they are now used for optical parameters optimization for application-specific camera design. In this experiment, a neural network is trained to estimate images or image quality indicators from optical parameters. However, the complexity and interconnectivity of optical parameters raises new challenges such as choosing the most relevant inputs with a suitable representation using limited available data. We investigated these challenges in the case of wide-angle systems. We tried to establish a data-driven prediction model to estimate the RMS spot size as a function of the distortion using mathematical or AI-based methods [12].

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