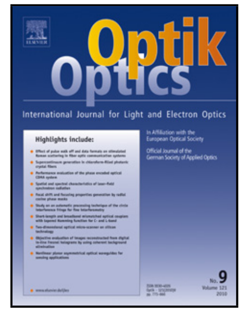
Accepted Manuscript



Title: Design of Parallel Wave-front Restoration Algorithm Based on FPGA

Authors: Jianlu Jia, Jianli Wang, Jinyu Zhao, Liang Wang, Xudong Lin, Xiaoxia Yang

PII: S0030-4026(18)31384-6
DOI: https://doi.org/10.1016/j.ijleo.2018.09.081
Reference: IJLEO 61520

To appear in:

Received date: 14-7-2018
Accepted date: 16-9-2018

Design of Parallel Wave-front Restoration Algorithm Based on FPGA

Jianlu JIA, Jianli WANG*, Jinyu ZHAO, Liang WANG, Xudong Lin, Xiaoxia YANG

Changchun Institute of Optics, Fine Mechanics and Physics, Chinese Academy of Sciences, Changchun 130033, China

*Corresponding author: wangjianli@ciomp.ac.cn

ABSTRACT

As the "brain" of the entire adaptive optical (AO)system, the processing ability of the wave-front processor determines the closed-loop control bandwidth and the correction effect of the adaptive optics. Wave-front restoration is the core of wave-front processing, and its operation delay is an important index for measuring the entire wave-front processing capability. In this paper, a high parallelism and extensible wave-front restoration algorithm is designed to upgrade and optimize the original algorithm in combination with the characteristics of the field-programmable gate arrays' high parallelism. Open-loop leveling and closed-loop correction experiments are conducted on 961- and 137-units deformable mirror AO systems. The experimental results demonstrate the feasibility and effectiveness of the proposed algorithm for the wave-front processing of large-scale AO systems.

Keywords: Parallel wave-front restoration algorithm; Adaptive optical system; Wave-front processor; Close-loop control; FPGA

1. INTRODUCTION

As a complex closed-loop system, the adaptive optical(AO)system is the union of optics, mechanics, electronics, and computer science. Improving ability and speed is always the conceptual goal.

With the growth of science and technology, higher requirements are needed for AO systems, owing to the appearance of larger-aperture telescopes with higher resolution. The dimensions of the AO systems (i.e., the numbers of the sub-aperture of wave-front sensor and the numbers of the deformable mirror) depend on the atmospheric coherence length r_0.The wave-front distortion caused by the atmospheric disturbance is well-compensated when the size of the sub-aperture of the wave-front sensor matches r_0. In the case of the 4-m aperture telescope, when $r_0$is 15 centimeter, the numbers of the sub-apertures are 710, and when $r_0$is 10centimeter, the numbers of the sub-apertures are 1,600 (Ref. [1]).

To accomplish such a complex wave-front processing task, a new generation of wave-front processors must be designed. They are distinguishable from traditional processors in the following ways (Ref. [2]) (Ref. [3]) (Ref. [4]).

1. Extensibility: because the AO systems require different wave-front processing and output capabilities, the wave-front processors must meet the needs of different scales of AO systems by extending the systems, saving economic and time costs.

2. Easy maintenance and upgrading: the basic requirements of most equipment. To avoid the large-scale modification of peripheral circuits, the core unit must be designed in a modular way to meet different processing needs by adding or decreasing modules to meet increasing demand.

3.Strong development environment: the wave-front processors must have a strong development environment that makes secondary development easy for users.

4.Strong processing capability: with the increase of system scale, the new wave-front processor has a strong wave-front processing capability and can complete the wave-front processing task in a very short time.

To meet requirements for wave-front processing of AO systems in our future 4-m or even larger aperture telescopes, it is necessary to design a new wave-front processor that can be extended to 1,000-units'level. New devices and methods should be sought. Moreover, because the AO technology is a core technology, there are only a few references and materials for design reference. The design of a wave-front processor that meets the characteristics of the new generation processor adapts to the size of different AO systems and has independent intellectual property rights. This is a very worthwhile topic to be studied.

2. THEORETICAL BASIS OF WAVE-FRONT MEASUREMENT, CALIBRATION AND CORRECTION BASED-ON SHACK-HARTMANN

The Zernike polynomials of a complete wave-front are described as follows (Ref. [5]),

$$\phi(x, y) = \alpha_0 + \sum_{k=1}^{n} \alpha_k Z_k(x, y) + \varepsilon, \tag{1}$$

where$\alpha_0$is the average wave-front phase, α_k is the k^{th} coefficient of the Zernike polynomial, $Z_k(x,y)$ is the k^{th} Zernike polynomial, and ε is the measurement error of the wave-front phase.

The relationship between the slope data in the sub-aperture and the coefficients of Zernike polynomials is as follows,