Control Algorithm for Adaptive Optics in Remote Sensing Telescope

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***Abstract*—We are developing an adaptive optics system for earth observing remote sensing sensor. In this system, high spatial resolution has to be achieved by a lightweight sensor system due to the launcher's requirements. Moreover, simple hardware architecture has to be selected to achieve high reliability. Image based AOS realize these requirements without wavefront sensor. In remote sensing, it is difficult to use a reference point source unless the satellite controls its attitude toward a star or it has a reference point source in itself. We propose the control algorithm of the deformable mirror on the basis of the extended scene instead of the point source. In our AOS, a cost function is defined using acquired images on the basis of the contrast in spatial or Fourier domain. The cost function is optimized varying the input signal of each actuator of the deformable mirror. In our system, the deformable mirror has 140 actuators. We use basis functions to reduce the number of the input parameters to realize real-time control. We constructed the AOS for laboratory test, and proved that the modulated wavefront by DM almost consists with the ideal one by directly measured using a Shack-Hartmann wavefront sensor as a reference.**

***Index Terms*—Adaptive optics, deformable mirror**

I. Introduction

For satellite remote sensing missions, high-resolution image is required. However, thermal deformation in orbit or mechanical vibration during launch degrades optical performance. The conventional space optical system used rigid structure to realize high optical performance. Consequently it is difficult to produce a lightweight and small sized sensor that is desired for small satellite missions [1].

The adaptive optics (AO), which compensates the optical performance in orbit automatically, is a key technology to realize lightweight and small sized optical sensor. In recent years, many deformable mirrors become available for small satellite missions because of its size and price. More than hundreds of actuates are enough to generate high accuracy wavefront, which compensate wavefront aberrations. One of the challenging issues is a control algorithm of the hundreds of actuators in real time compensation.

Comparing with the AO of the astronomical telescopes, main differences are the source of the wavefront aberration, and the time constant of the aberration change. The sources of the wavefront aberration of the remote sensing satellite are thermal deformation or misalignment of the optical elements instead of disturbance of the atmosphere. Usually the thermal deformation occurs due to the orbital motion. The period of the deformation is almost one and a half minutes, which is slower than atmospheric disturbance. For AO systems, optical wavefront measurement is one of the main issues. We estimate the optical wavefront using observed images instead of using a Shack-Hartmann wavefront sensor. This aims to make simple hardware architecture, and to avoid calibrating the wavefront sensor. When we estimate wavefront using observed images, it is difficult to use a priori information about observed scenes. Image based wavefront estimation makes it possible to introduce all incident light flux into image sensor to improve signal to noise ratio. Furthermore, all degradation factors can be compensated because they affect the quality of the observed image.

One of the image based wavefront estimation technique is known as phase diversity wavefront sensor [2]. In this method, wavefront aberration is formulated by mathematical model. This means that modeling accuracy is important to use phase diversity method.

Another approach is compensating wavefront aberration controlling deformable mirror actuators directly using observed images as a cost function. In this method, modeling of the wavefront aberration is not necessary. On the other hand, it need long time to optimize the cost function, because an image has to be acquired for iteration of optimization step. A fast optimization algorithms are introduced to real time wavefront compensation [3].

The purpose of our work is to propose AO control algorithm for satellite remote sensing missions, in which observed images are extended scene instead of point source like a star and observed image changes due to orbit motion of the platform satellite.

II. Wavefront Compensation Method

A. Cost Function to Compensate Wavefront Aberrations

We use the contrast of the image as a cost function C (Eq. (1)). L_{max} is the maximum pixel value and L_{min} is the minimum pixel value.

$$C = \frac{L_{\max} - L_{\min}}{L_{\max} + L_{\min}}. \quad (1)$$

When different area, for example urban area and ocean, the value of C might be large value irrespective of the actual contrast of the image. We use the small patch of the image to prevent this problem.

B. Input Parameters for Optimization Problem

We use each actuator as input parameters for optimization problem. In our system, there are 140 actuators in the deformable mirror, which controls the wavefront aberration.

III. RESULTS

A. Conditions of a Numerical Simulation

We assume that the relation between the input signal of the deformable mirror actuators and the generated wavefront is known. The relation has to be calibrated prior to the optimization process. The parameters of the Zernike polynomial [4] functions are used as input parameters of the optimization problem.

B. Results of a Numerical Simulation

The result of the wavefront compensation is shown in Figure 1. An aberrated image is improved by deformable mirror control on the basis of the contrast of the image patch. This image almost consists with a diffraction limited image.

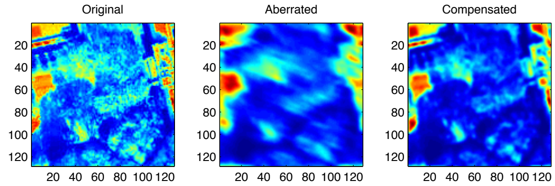

Figure 1. Improvement of the quality of the observed image, (left) original image, (center) aberrated image, (right) compensated image.

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