Development & Testing of Shack-Hartmann Wavefront Sensor Using Zonal Approach

Sudhabrata Majumder, Vijayeta Gambhir, D.P. Ghai.
Laser Science and Technology Center, Metcalfe House, Civil Lines, Delhi 110054. INDIA.

ABSTRACT

This paper describes the design and testing of a Shack-Hartmann Wavefront Sensor (SHWFS). This SHWFS will be implemented as the wavefront (WF) sensor in closed loop Adaptive Optical (AO) System. This SHWFS comprises of a 16x16 lenslet array each having 300µm diameter and a focal length of 24mm. The lenslet array is glued to the C-mount of CCD array, obviating the need of any other relay lenses. The CCD camera is having a format of 532x516 pixels and a frame rate of 262 frame/sec interfaced with a PI XI-D frame-grabber card of 100MB/sec data transfer rate. The wavefront processing is carried out with a Pentium-IV, 2.4 GHz computer. Multi-threaded concept of VC++ has been exploited for simultaneous operation of capturing the optical wavefront, estimating the centroid shift and finally reconstructing the wavefront. Southwell geometry is used for reconstructing the phase plot.

The sensor is tested by producing phase plots of wavefronts generated by a Single Actuator Deformable Mirror (SADM). This SADM was indigenously fabricated with the silicon face-sheet (1'' dia, 2mm thick) bonded to a single PZT actuator. The phase plots are obtained by driving SADM from 0 to 150volts at intervals of 10 volts. The reference wavefront is created by biasing the actuator with 75volt. Relative phase values are also measured at varying voltages and plotted.

Keywords: Wavefront Sensor, Deformable Mirror, Adaptive Optics, Wavefront Reconstructor.

INTRODUCTION

Optical signals get abberated mainly due to naturally occurring temperature variation in the atmosphere in the course of their propagation, which deliberately forms an image. Shack-Hartmann Wavefront Sensor was designed to measure the optical phase and intensity profile in real-time with high accuracy.

PRINCIPLE & THEORY

In the Shack-Hartmann wavefront sensor the whole optical beam is subdivided in to a number of beam-lets using a two-dimensional micro-lenslet array. Each sub aperture provides a separate focal spot onto the CCD detector. If there is any distortion in the wavefront the focal spot gets shifted from its original position. A computer program measures this displacement. A typical Shack-Hartmann spot pattern is shown in figure 1.

![Figure 1: The micro-lenslet array arrangement and Shack-Hartmann pattern.](image-url)
The grid configuration of Shack-Hartmann wavefront sensor is shown in this figure 2.

![Figure 2: Grid Configuration of SHWFS](image)

Let us consider the phase relation between the x-direction is represented by the polynomial

\[ \phi = c_0 + c_1 x + c_2 x^2 \quad (i) \]

The slope is given by the first derivative of the

\[ \frac{\partial \phi}{\partial x} = c_1 + 2c_2 x \quad (ii) \]

If we solve the equation (i) by equation (ii) at boundary condition (x=h), the phase value will be \( \phi_{i+1} \). The equation (i) will become

\[ \phi_{i+1} - \phi_i = \left( \frac{\partial \phi}{\partial x} \right)_{i+1} h \quad (iii) \]

Equation (iii) has been solved for both the direction x as well as y using matrix iterative method to evaluate the relative phase value \( \phi \).

**DESCRIPTION OF MEASUREMENTS**

The schematic of experimental setup as well as photograph of actual setup are shown in the figure 3 & 4 respectively.

![Figure 3: Schematic of SH-WFS.](image)

![Figure 4: Actual Setup of SH-WFS.](image)
A single actuator Deformable Mirror produces the wavefront deformation. A power supply and a signal generator drive the Deformable Mirror. The He-Ne laser beam is expanded by a 10X beam expander and divided by a beam splitter. After reflected from the DM the beam falls on the CCD sensor through a 16x16 micro-lenslet array. The deformation is detected by processing the frames provided by the CCD camera to the frame grabber card, installed inside a personal computer (p-iv).

Multithreaded software has been written in VC++ on windows 98 environments to synchronize the capturing, analyzing & displaying the analyzed data in real-time. The main GUI of the software is shown in the figure 7. The algorithm is shown using the flow chart.

Figure 5: Algorithm for Shack Hartmann Wavefront Sensor

The wavefront sensor is used to measure the focus and defocus of a single actuator deformable mirror of 1-inch dia. The driving range of the PZT actuator is from 0 to 150volt. Keeping the actuator at 75volt the reference image has been captured. Then the voltage increased up to 150volt, as well as decremented up to 0volt at a step size of 15 volt. The three-dimensional phase plot and voltage vs. relative phase value is shown in the figure 6 and Figure 7 respectively.

Figure 6: Voltage Vs. Relative Phase Plot
We have employed a 16x16 lenslet array each having 300µm diameter and a focal length of 24mm. The lenslet array is glued to the C-mount of CCD array. The CCD camera is having a layout of 532x516 pixels and a frame rate of 262 frame/sec interfaced with a PIXI-D frame-grabber card of 100MB/sec data transfer rate. The wavefront processing is carried out in Pentium-IV, 2.4 GHz computer.

CONCLUSION & FUTURE WORK

Developed Shack-Hartmann Wavefront sensor has to be integrated in closed loop system to nullify the wavefront distortion in realtime.

REFERENCES