DST PSF Estimation from AO Data - Data Collection

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Given $n$ sets of variates denoted \( \{x_1\}, \ldots, \{x_n\} \), the covariance $\sigma_{ab} \equiv \text{cov}(x_a, x_b)$ of $x_a$ and $x_b$ is defined by

\[
\text{cov}(x_a, x_b) \equiv \langle (x_a - \langle x_a \rangle)(x_b - \langle x_b \rangle) \rangle
\]

\[
= \langle x_a x_b \rangle - \langle x_a \rangle \langle x_b \rangle
\]
Covariance matrix

The matrix \((V_{ab})\) of the quantities \(V_{ab} = \text{cov}(x_a, x_b)\) is called the covariance matrix. If there are 6 variates,

\[
\begin{align*}
\text{cov}(x_1, x_1), & \quad \text{cov}(x_2, x_1), \quad \text{cov}(x_3, x_1), \quad \text{cov}(x_4, x_1), \quad \text{cov}(x_5, x_1), \quad \text{cov}(x_6, x_1) \\
\text{cov}(x_1, x_2), & \quad \text{cov}(x_2, x_2), \quad \text{cov}(x_3, x_2), \quad \text{cov}(x_4, x_2), \quad \text{cov}(x_5, x_2), \quad \text{cov}(x_6, x_2) \\
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\end{align*}
\]

The covariance is symmetric since \(\text{cov}(x, y) = \text{cov}(y, x)\)
For PSF reconstruction of an image using data from the AO control loop during the exposure time of the image, two covariance matrixes are needed.

1. The covariance matrix of the subaperture shifts in x and y. For 76 subapertures there are 152 variates and the matrix is 152x152.

2. The covariance matrix of the actuator positions. For 97 actuators the matrix is 97x97.
In a real time AO system, two ways of obtaining these matrixes are:

1. All the x, y and actuator values during the exposure are saved and the covariance matrixes are calculated later.

   The AO system runs at 2500 frames per second. For a 3 second exposure, there would be

   \[(76x + 76y + 97\text{ actuators}) \times 3\text{ seconds} \times 2500\text{ frames/second} = 1,867,500\]

   values that would need to be stored in the real time system and then read out and processed.

   Exposure time is limited by the storage capability of the real time system. Science image rate is limited by the time required to read the data out of the real time system.
2. The variates and their products are summed in real time. The sums are read out of the AO system at the end of the exposure and the matrixes are generated in the host PC.

There are an additional 11628 multiply/adds plus 249 adds for the real time system to do each frame.

There is no limit on the length of exposures.

There are only 11877 values to read out of the real time system.
DST AO76
Block Diagram

- Baja AO76 Camera
- Camera Power Supply
- Camera DSP Interface
- cPCI Chassis
- D/A
- Tip Tilt Driver
- Tip Tilt Mirror
- DST Camera System TTL Expose Pulse
- Mirror Interface
- Mirror Driver
- Deformable Mirror
- Mirror PC
- Keyboard
- Monitor
- Motor Controller
- WFS field stop motor
- WFS focus lens motor
- WFS focus
- WFS lens motor
- com1
- com2
Data and control path for DSP cluster

8 images → Sum of $x, y, x^2, y^2, xy$ for each image → 4 images

4 images → Sum of $x, y, x^2, y^2, xy$ for each image → 2 images

2 images → Sum of $x, y, x^2, y^2, xy$ for each image

2 images → Sum of $x, y, x^2, y^2, xy$ for each image

97 partial reconstruction matrix multiply results and shift x’s & y’s

To next cluster

From previous cluster

Control signals for COV and data collection
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**COV Matrix for shifts**
Each DSP processes one or two subapertures and keeps the sum of the x and y values for those subapertures. It also keeps the sum of the square and product of those x and y values.

All the x and y values are also passed to one DSP which sums the products of the rest of the matrix.

One DSP also sums the actuator values and products for the actuator matrix.

At the end of the exposure, the host PC reads the sums, calculates the means, generates the two matrixes and writes them to a file.
Uncorrected Light

97 Actuator Deformable Mirror

Correlation and Reconstruction DSPs

CCD Camera

Shack-Hartmann Lenslet Array

Beam Splitter

Tip/Tilt Mirror

Switch

From Correlation Tracker

Corrected Light

Adaptive Optics
Adaptive Optics

National Solar Observatory
Sacramento Peak, Sunspot New Mexico