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CAOS Simulation Package 3.0: an IDL-based Tool for Adaptive Optics Systems Design and Simulations

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Abstract. The IDL-based simulation software Code for Adaptive Optics Systems (CAOS) was originally developed to simulate the behavior of generic adaptive optics systems. The modular structure of the software allows the simulation of a great variety of different systems and is particularly suited for the adoption of graphical techniques for the programming of applications. It is actually composed of a global user interface (the CAOS Application Builder – presented in Fini et al. 2001), and a set of specific modules: the CAOS Simulation Package. We present in this paper the last version (3.0) of the CAOS Simulation Package, together with an example of an application to the Large Binocular Telescope interferometer adaptive optics system.

1. Introduction

In the framework of the "Laser Guide Star for 8-m Class Telescopes" *Training and Mobility of Researchers* network funded by the European Union, an IDL-based software package has been developed to simulate generic adaptive optics (AO) systems. The structure of the software is modular. Each elementary physical process such as turbulence in atmospheric layers, propagation of light from source to observing telescope and through the turbulent layers, the wavefront sensor, is modeled in a specific module. The resulting software, called Code for Adaptive Optics Systems (CAOS), is composed of a global graphical user interface (GUI), the CAOS Application Builder (Fini et al. 2001), and a set of specific modules—the CAOS Simulation Package. A list of modules and brief descriptions are presented in Section 2. An example of an application to the Large Binocular Telescope (LBT) interferometer AO system is presented in Section 3. References to more information about CAOS are given in Section 4.

2. The Modules of CAOS Simulation Package 3.0

Table 1 shows a complete list, together with a very brief description, of the modules of CAOS Simulation Package 3.0.

Table 1. Descriptive list of the modules.

Module	Purpose
wavefront generation modules	
`ATM - ATMosphere building`	to simulate the turbulent atmosphere
`SRC - SouRCe definition`	to define the observed source
`GPR - Geometrical PRopagation`	to propagate the light
LGS-specific modules	
`LAS - LASer generation`	to define the projected laser beacon
`NLS - Na-Layer Spot building`	to simulate the 3D sodium LGS
wavefront correction modules	
`TTM - Tip-Tilt Mirror`	the tip-tilt correcting mirror
`DMI - Deformable MIrror`	the deformable correcting mirror
wf sensing and reconstruction	
`TCE - Tip-tilt CEntroiding`	to reconstruct the tip-tilt
`SHS - Shack-Hartmann Sensor`	to simulate the Shack-Hartmann sensor spots formation
`CEN - CENtroiding calculus`	to compute the SH centroids
`TFL - Time FiLtering`	to emulate commands time-filtering
`REC - REConstruction module`	to reconstruct the wavefront
calibration-oriented modules	
`CFB - Calibration FiBer`	to define a calibration fiber
`CSQ - Command SeQuencer`	to generate calibration commands
`MCA - Make CAlibration data`	to elaborate calibration data
other scientific modules	
`IBC - Interf. Beam Combiner`	to simulate co-phasing of two beams
`IMG - IMager module`	to simulate image formation
`STF - STructure Function`	to compute the structure function
`WFA - WaveFront Adding`	to linearly combine two wavefronts
`BSP - Beam SPlitter`	to emulate a beam-splitter device
utility modules	
`PSG - Phase Screen Generation`	to generate turbulent phase screens
`DIS - data DISplay utility`	to display any kind of input data
`SAV - data SAVing utility`	to save cubes of data (`XDR` format)
`RST - data ReSTore utility`	to restore `XDR` cubes of data

Using the CAOS Application Builder, a simulation can be built by connecting together the required occurrences of the desired modules, represented by the boxes of Figure 1. The only constraints are those imposed by input/output types. Each module comes with an individual GUI in order to set its own physical and numerical parameters, during the design step or independently at a

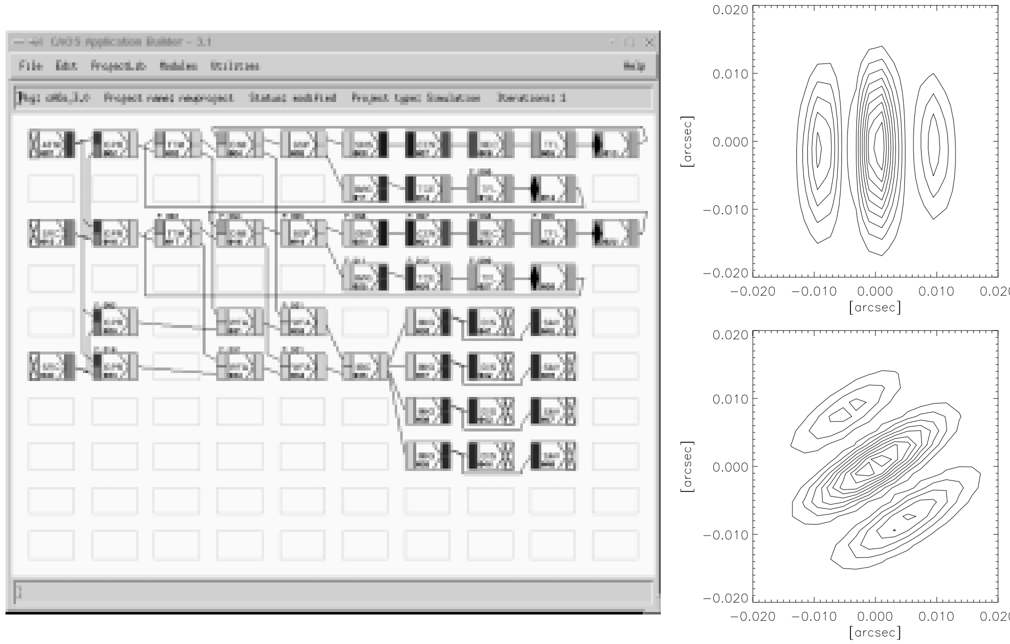

Figure 1. The CAOS worksheet corresponding to the LBT interferometer (left), together with the contour plots of two of the obtained PSFs: R-band, 1″ off-axis, parallactic angle of 0° (up), and 120° (down).

later time. The whole structure of a simulation can be saved as a "project" that can be restored for later modifications and/or parameters upgrading. The IDL code, corresponding to the designed simulation, is written down during the saving of a project, and it can be modified "by hand" in order to be completed with additional tasks not supported by the CAOS package.

3. An Example of an Application to the LBT Interferometer

Let's assume that we would like to simulate high-angular-resolution observations in the red and near-infrared wavelength bands[1], with the LBT interferometer[2] and with AO correction. Figure 1 (left) shows the whole project designed for such a purpose, with a natural guide star (NGS) of 10^{th} magnitude for the AO sensing, either on-axis or 1″ off-axis with respect to the astronomical object. The turbulent atmosphere is modeled with two layers: a ground layer evolving along the baseline and weighted with 30% of the total turbulent energy, and an upper layer (at 10 km altitude) evolving orthogonally to the baseline and weighted with 70% of the total turbulent energy. For both layers the wind speed is 5 m/s. The total Fried parameter r_0 is 20 cm (at 500 nm), and the wavefront outer-scale L_0 is 40 m. Each pupil of the LBT interferometer has its

[1]namely R (700±110 nm), J (1250±150 nm), H (1650±=175 nm), and K (2200±200 nm)

[2]2×8.25 m with a 14.4 m baseline

own AO system made of a tip-tilt (TT) correction loop, and a high-orders (HO) correction loop. The HO loop is made of: a 34×34 Shack-Hartmann lenslet array with 8×8 pixels/sub-aperture and 0.15″/pixel for the sensing, a modal rejection of the Zernike modes over number 231 (20^{th} radial order) during the wavefront reconstruction, and a 35×35 actuators deformable mirror (that corresponds to a projected inter-actuator distance of ∼23.5 cm on the primary mirror) for the correction. The TT loop contains a quad-cell detector (with 0.25″/cell). Both sensings are performed in R, the light from the NGS being split 95% for the HO loop and 5% for the TT loop, assuming an overall efficiency of 60% and a read-out noise of 3 $e^{-}rms$. The time-filtering acts in each loop as a pure integrator, and the differential piston is supposed to be perfectly corrected. The scientific CCD – on which the point-spread function (PSF) corresponding to the astronomical object is formed – make 128×128 pixels images[3]. The total temporal history of each simulation run – one per value (0°, 60°, and 120°) of the parallactic angle – is 2.075 s (corresponding to 415 iterations of 5 ms each), but the resulting interferometric PSFs (one per band (four) and per off-axis (two) considered) are integrated over the last 2 s for sake of AO stability. For each of the simulation run, a different realization of the turbulent atmosphere was considered (since each parallactic angle corresponds to a different period of the observing run). Figure 1 (right) shows two of the 3×4×2 obtained PSFs, while Table 2 synthesizes the quality of all the 24 AO-corrected interferometric PSFs obtained in terms of Strehl ratio.

Table 2. Strehl ratios obtained for each of the interferometric PSF.

0″	R	J	H	K
0°	.606	.851	.907	.946
60°	.581	.836	.897	.939
120°	.557	.816	.878	.921

1″	R	J	H	K
0°	.554	.827	.893	.938
60°	.522	.809	.881	.929
120°	.504	.791	.864	.912

4. More Information...

For more information and references on the CAOS Simulation Package and the CAOS Application Builder, see `http://www.arcetri.astro.it/caos`. See also Correia et al. (2001) for a description of the CAOS-compatible simulation package AIRY (Astronomical Image Restoration in interferometrY).

References

Fini, L., Carbillet, M., Riccardi, A. 2001, this volume, 253

Correia, S., Carbillet, M., Fini, L., et al. 2001, this volume, 404

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[3]with ∼2.1 mas/pixel in R, ∼3.8 mas/pixel in J, ∼5.0 mas/pixel in H, and ∼6.7 mas/pixel in K