KASP Technical notes #01:
KECK-like AO system end-to-end simulations pipeline coded into OOMAO

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1 Purpose

KASP, standing for Keck Ao Simulation Pipeline, is designed for providing a end-to-end simulations tools for the Keck adaptive optics system, in the prospects of performing PSF-reconstruction (PSF-R) for a segmented pupil of 10m class. The code is mainly supported by OOMAO (Object-Oriented Matlab Adaptive Optics) coded into Matlab ([1]), that simulates the electric field propagation through the atmosphere, telescope and adaptive optics system. KASP allows to simulate any AO system in a SCAO/LGSAO/GLAO configuration so far, and will be extended to LTAO, especially in the context of PSF-R with Harmoni on the E-ELT. We describe through this document the main facilities and how to use KASP.

2 Code architecture

2.1 Main facilities

OOMAO is object-oriented and invokes different Matlab classes (source, telescope, atmosphere, dm, wfs) which are handled for propagating the wave-front through all the system. On top of that, KASP includes

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additional classes for simulating a AO loop from a parameter file only (as it's done with YAO on Yorick) :

- **systemSimulator class**: this class instantiates all the AO system from a parameters file.
- **realTimeController class**: gathers all control laws and is called during the simulation for updating the DM commands.
- **errorBreakdown class**: independent tools that provides in the same time the end-to-end simulation plus a detailed error breakdown. See KASP note# 6 for more details.
- **psfR class**: PSF-R taking the systemSimulator class as an input for reconstruction the PSF from the simulated telemetry. See KASP note #2 for more details.
- **psfStats class**: here is a facility for estimating and storing the properties (Strehl,Ensquared energy, FWHM) of a PSF.See KASP note# 4 for more details.
- **fourierModel class**: calculation of AO errors PSDs and then the PSF from the systemSimulator class using the Fourier description of the residual phase. The code has been originally written by C. Correia under the call spatialFrequencyAdaptiveOptics in the root folder of OOMAO.
- **crowdedFields class**: simulate a crowded field from a catalog ([**?**]).
- **quasiStellarObjects class**: simulate a quasi stellar object profile from a Sersc profile plus a central Dirac function. The profile is then convolved by a PSF given as an input to the class.

2.2 The parameter file

The parameter file must be named 'parFileXXX' and only the XXX part is provided to the systemSimulator class. Tab. 1 summarizes all the parameters allowed to be simulated into KASP so far. Simulations of multiple WFS systems are feasible in providing a vector for guide stars locations and a flag dedicated to the tomographic process. If a tip-tilt sensor is defined, the systemSimulator class is designed to filter out tip-tilt measurements on the high-order WFS and it is also possible to perform tip-tilt tomography.

KASP includes also a dedicated tool for generating segmented pupil including both reflexivity and phase errors, as co-phasing or gravity-induced errors, by providing a vector of Zernike coefficients per segment. See KASP note# 6 about how to use of this facility.
Also, you may need to import external data to simulate for finely your system as influence functions, real pupil shape or NCPA residual phase map, that is made available in KASP in filling the appropriate systemSimulator fields with your data or paths.

Scientific target	
magSrc	Target magnitude (Ex: 12).
photoSrc	Target photometry (Ex: photometry.H).
heightSrc	Science target height.
[xSrc,ySrc]	Target location in arcsec (Ex: [-10,0]).
Atmosphere	
photoAtm	Wavelength the atmosphere parameters are defined at.
r0	Fried's parameter in meter.
L0	Outer scale value.
windSpeed	Wind speed per layer.
windDirection	Wind directions per layer.
fractionnalR0	Relative strength per layer.
layerAlt	Turbulent layer altitudes.
Telescope	
nResTel	Pupil size in pixel.
D	Pupil diameter in meter.
obs	Central obstruction in D unit.
fovTel	Telescope field of view in arcsec
Fe	Temporal frequency of atmosphere screens update
zenithAngle	Telescope zenith angle in degree.
Segmented pupil	
usePupilClass	Set to one to use the pupil class facility.
segNSides	Number of segment sides.
segRadius	Segment radius (unsubscribed circle) in meter.
segNPixels	Segment resolution in pixel.
segmentCoordinates	Segment center coordinates.
pupilUnit	Coordinates units ('px' or 'm').
noGap	Set to 1 to fix the segment gap issue.
pupilSpider.n	Number of spiders.
pupilSpider.angle	Angle position of spiders.
pupilSpider.width	Spiders width in pixel.
pupilCoeffPhaseModes	Segments phase Zernike coefficients.
pupilReflexivity	Segments reflextivity.
Guide star sources	
magGs	Guide stars magnitude.
photoGs	Guide stars photometry (Ex: photometry.Na)
heightGs	Guide stars height.
nLgsPhoton	Photon return for LGS sources.
naProfile	Sodium density profile.
lgsfwhm	Spot kernel size in arsec when using LGS.
[xGs,yGs]	Guide stars locations.
High-order WFS	
nL_ho	Number of lenslets.
nPx_ho	Number of pixel per sub-aperture.
ps_ho	Pixel scale in arcsec/pixel.
thres_ho	Brightest pixel threshold.
ron_ho	Read-out noise in e- rms/pixel
phNoise_ho	Set to 1 for including photon noise.
throughput_ho	WFS optics throughput.
Tip-tilt sources	
mag_tt	Tip-tilt stars magnitude.
photo_tt	Tip-tilt stars photometry
[x_tt,y_tt]	Guide stars locations.
Tip-tilt WFS	
nL_tt	Number of lenslets for the TT WFS.
nPx_tt	Number of pixel per sub-aperture for the TT WFS.
ps_tt	Pixel scale in arcsec/pixel.
ron_tt	Read-out noise in e- rms/pixel
phNoise_tt	Set to 1 for including photon noise.
throughput_tt	TT WFS optics throughput.
Low bandwidth source	
mag_ts	Truth sensor stars magnitude.
photo_ts	Truth sensor stars photometry
[x_ts,y_ts]	Truth sensor location.
Low bandwidth truth sensor	
nL_ts	Number of lenslets for the TS.
nPx_ts	Number of pixel per sub-aperture for the TS.
expTime_ts	TS WFS exposure time in atmosphere sampling period unit.
ps_ts	Pixel scale in arcsec/pixel.
thres_ts	Brightest pixel threshold.
ron_ts	Read-out noise in e- rms/pixel
phNoise_ts	Set to 1 for including photon noise.
throughput_ts	TS WFS optics throughput.
Science imaging camera	
clockRate	Imaging camera clock rate in atmosphere sampling period unit.
exposureTime	Exposure time in frames.
startDelay	Number of waiting temporal frames before buffering images.
ps_img	Pixel scale in arcsec/pixel.
camRes	Camera CCD resolution.
ron_img	Read-out noise in e- rms/pixel
phNoise_img	Set to 1 for including photon noise.
Deformable mirror	
nActu	Number of DM actuators.
coupling	Actuators mechanical coupling
Loop set up	
g_ho	High-order loop gain.
lat_ho	High order loop latency in seconds.
g_tt	Tip-tilt loop gain.
lat_tt	Tip-tilt loop latency in seconds.
g_ts	TS loop gain.
External data	
pupilTel	Map containing the telescope pupil at nResTel resolution.
ncpaMap	Map containing the NCPA residual phase map in radian at nResTel resolution.
ncpaWvl	Imaging wavelength during NCPA calibration in meter.
psfNCPA	
validSubapMap	
validActuatorMap	
iFpath	
pathInteractionMatrix	
pathCommandMatrix	
pathTomoReconstructor	
Flags	
flagSH	1 for a diffrative SH and 0 for a geometric one.
flagTomo	'none','mean', 'mmse-mvm' or 'mmse-recursif'.
flagTomoTT	'none','mean', 'mmse-mvm' or 'mmse-recursif'.
dmControl	'integrator' or 'polc'.
ttDmControl	'integrator' or 'polc'.
controlBasis	'zonal' or 'modal'.
parallelPhaseOnly	Set to 1 to simulate only AO in-band spatial frequencies.

Table 1: Summary of parameters including into KASP simulation. Bold part represents required parameters for simulating the system.

2.3 How to use

The using of the systemSimulator class is very friendly. If your parameter file is named 'parFileKeckNGSAO' for instance, you only have to do the following call :

```
sys = systemSimulator('KeckNGSAO','runSimu',1,'parallelPhaseOnly',0,'disp',0,...
'flagMoffat',0,'flagGaussian',0);
```

where all the field following the parameters file are not required :

- runSimu : set to 1 to run the end-to end simulation.
- parallelPhaseOnly : set to one to simulate an atmospheric phase with only AO in-band correction spatial frequencies.
- disp : set to 1 to have some display during the simulations.
- flagMoffat : set to one to perform a Moffat fitting on the imaging camera PSF after upstream the simulation.
- flagGaussian : set to one to perform a Gaussian fitting on the imaging camera PSF.

3 Conclusions

We've presented the main structure of KASP and how to use the systemSimulator class in the purpose of simulating easily an AO system from a parameter file.

References

[1] R. Conan and C. Correia. Object-oriented Matlab adaptive optics toolbox. In *Adaptive Optics Systems IV*, volume 9148 of *Proc. SPIE* , page 91486C, August 2014.