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SIMULATIONS OF WAVE FRONT MEASUREMENTS AND TOMOGRAPHY FOR EXTREMELY LARGE TELESCOPES

M. Chebbo[1], B. Le Roux[2], J.F. Sauvage[3] and T. Fusco[4]

Abstract. The control of AO systems dedicated to ELT is a difficult problem related to the large number of degrees of freedom. The standard and most used adaptive optics AO control starting from the integrator to the LQG are not useful in such a case. In fact, for future Extremely Large Telescope (ELTs) the number of degrees of freedom is very large related to the large diameter of the ELTs and the emergence of new architectures for the AO systems. So that the necessary computational power for real time control RTC on such systems is currently unattainable when using these control methods. Thus, more efficient algorithms are required. We present simulation results of a tomographic AO system in the configuration of EAGLE instrument (multi-object adaptive optics).

Keywords: adaptive optics, inverse problem, reconstruction, sparse matrix

1 Introduction

In this article we describe an adaptive optics simulation platform, which can be used to simulate adaptive optics systems on the largest proposed future extremely large telescopes ELT. This simulator is based on a sparse library created by RALPH Flicker, it's a sparse Operations with Yorick/IDL originates from a collection of IDL/C routines that are used together for a specific purpose: efficient wave front reconstruction in adaptive optics simulations*.We introduce a solution for a fast wavefront recontructions and then the results for simulations and reconstructions done over an octopro 2.1GHZ.

2 E2E CAOS simulations

The CAOS ”system” (Code for Adaptive Optics Systems) is properly said a Problem Solving Environment (PSE) (Carbillet et al. 2004). MAOS (that stands for Multiconjugate Adaptive Optics Simulations) developped for multi-reference multiconjugate AO studies purpose. PAOLAC which is a simple CAOS interface for the analytic IDL code PAOLA (Carbillet et al. 2005) . The first step of our work consisted in validating the computing capabilities for ELT simulations. First of all, using a standard biprocessor computer, we simulated classical adaptive optics with CAOS for different telescope diameters, from 8m to 28m. For larger telescopes, the biprocessor computer was not able to make the simulation (see Figure1) . Our second step consisted in simulating classical adaptive optics on an octoprocessor computer so that we reached a 42m telescope . We present the simulation time for the different simulation reached by a bi and octoprocessor. For a 42m, 8 hours of simulation are required. Moreover the simulation of GLAO FOR 28m telescope on an octoprocessor, using 4 guide stars on the border of a 40 arcmin field of view. The deformable mirror is 31×31 actuators and the Shack-Hartmann WFS is 30×30 sub-apertures. The atmosphere is composed of 4 turbulent layers at 10, 100, 1000 and 5000 m of altitude the E2E simulation times tooks 1 day. As a conclusion, the dramatic increase of the number of degrees of freedom while simulation AO for the ELT makes our work more difficult using CAOS. For those reasons we are going to introduce the SOY/I library created by Ralf-Flicker in the purpose of an efficient wave front reconstruction in adaptive optics simulations.

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[1] Laboratoire d'Astrophysique de Marseille
[2] Laboratoire d'Astrophysique de Marseille
[3] ONERA, BP 72, 92322 Chatillon cedex, France
[4] ONERA, BP 72, 92322 Chatillon cedex, France

*see Ralf Flicker's site `http://homepage.mac.com/rflicker/soy.htm`

3 Modelization of a Shack-Hartmann

The purpose of this chapter is to analyse the noise introduced by a SH on the slopes of an incident WF and to reconstruct a wave front given the measurements, all by using the real matrix and the generalized inverse.

In fact, a model of the wave front sensor allows to link the measurement S to the incoming phase ϕ. It can be written as

$$S = D\Phi$$

3.1 Zonal approach

In order to determine the matrix D of N*M elements, we are going to use the finite difference to express the slopes in terms of the discrets phase values. Considering the Shack-Hartmann with square subaperatures, and by using the Frieds model (Rousset 1999) :

$$S^x_{ij} = [(\phi_{i+1j+1} + \phi_{i+1j}) - (\phi_{ij} + \phi_{ij+1})]/2d$$
$$S^y_{ij} = [(\phi_{i+1j+1} + \phi_{ij+1}) - (\phi_{ij} + \phi_{i+1j})]/2d$$

Where D is the interaction matrix. Created by four diagonals corresponding to the response of WFS on each phase ϕ_{ij} at the corner of each subaperature. So the elements of D are $\pm(2d)^{-1}$ or 0. By using the inverse problem and given the measurement we are able to estimate the phase:

$$\hat{\phi} = D^{\dagger}S$$
$$D^{\dagger} = (D^T D)^{-1}D^T$$

We verify in Figure 2 that the power spectral density introduced by the subaperatures of a Shack-Hartmann in the phase slopes follows the inverse of the square of the special frequency.

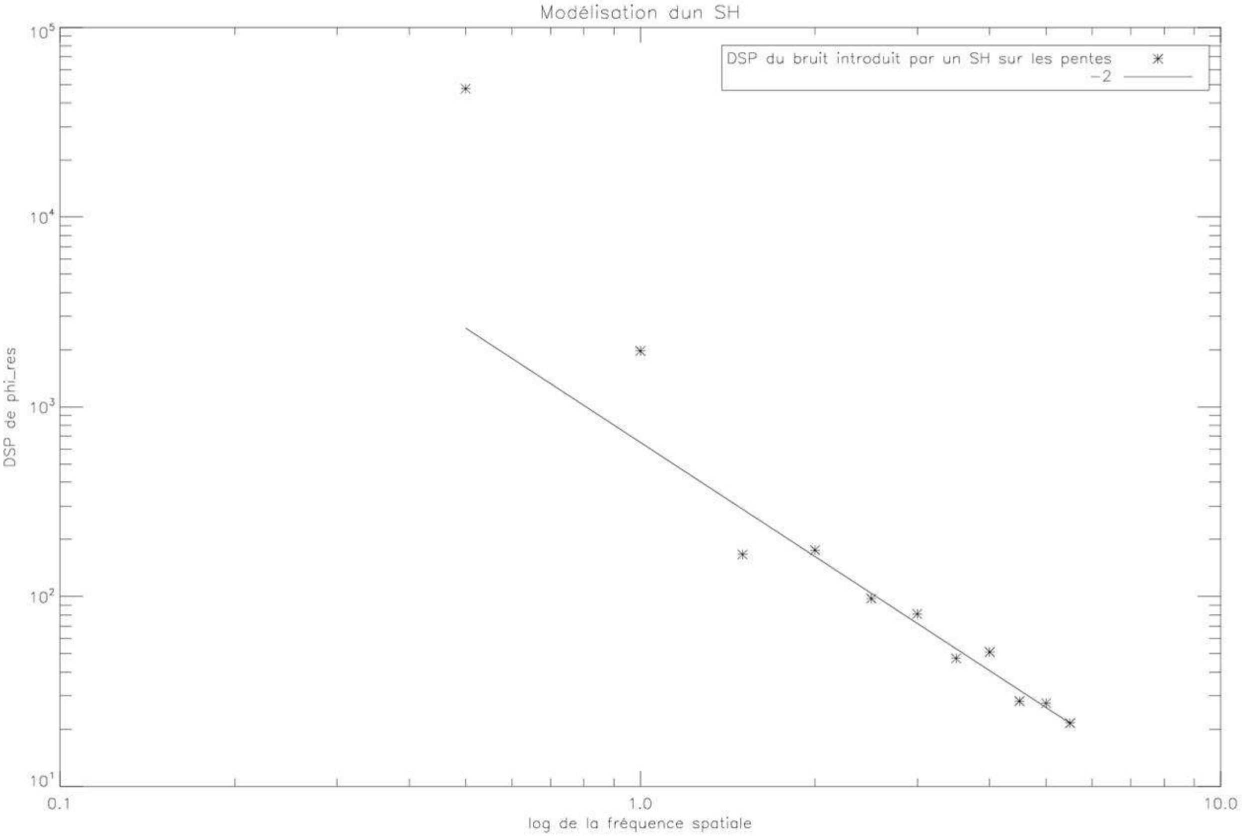

Fig. 1. DSP on the meausurement intruduced by a SH

4 E2E Sparse Matrix Simulator

4.1 Volume phase reconstruction

We generate a turbulent phase corresponding to each layer (see Figure 4), then we build a matrix in a sparse format giving the number of none zero elements to be stored for each direction and each layer. This matrix provides the projection of the phase in the pupille coming from all the analyses directions, supposed that we have 3 layers and 5 directions this matrix is $(N^2 \times 5, N^2 \times 3)$

$$\phi_a = I\phi_c$$

The estimation of the wave front given the measurement in the different directions is an inverse problem which must be solved using proper regularization in order to improve the quality of the solution while avoiding noise amplification or ambiguity due to missing data. Estimating the phase requires the inversion of the covariance matrix, moreover for the ELT the number of actuators being considered is in the range $10^4 - 10^5$, so the inversion of the covariance matrix using the present methods needs a lot of time to calculate and a huge memory to store, moreover those present reconstructor scales more than $O(N^2)$.

$$\hat{\phi} = (I^T I)^{-1} I^T \phi_{mes}$$

To avoid the direct matrix inversion we propose to use an iterative method with Jacobi preconditioner to solve the linear system :

$$(I^T I)\hat{\phi} = I^T \phi_{mes}$$

Where the first factor is a symmetric positive definite sparse matrix, and the MVM (matrix-vector multiplications) is carried out sparsely by the `ruoxv(a,v)` function.

4.2 Simulation results

For a telescope 190×190 pixels in the metapupil, $R_0 = 0.159$m and RSB $= 20$ in 5 arcmin. We show the estimated phase in four layers as it is shown in Figure 5, given the measurements from Figure 3.

Fig. 2. The wave front measurement in nine directions for a 42 m in 5 arc min

As a conclusion of this section, we generate a turbulent wave front in the layers, using a projector matrix built in a sparse format and providing a bilinear interpolation we project the phase in the pupille, we add the wave front sensor noise, then using an iterative methode and the jacobi preconditioner we solve the linear probleme in order to estimate the phase corresponding to the different layers.

5 Computing time characterization of the E2E Sparse Matrix code

Since we are looking to simulate AO for ELT, its important to proove that we have a fast wave front reconstructor.

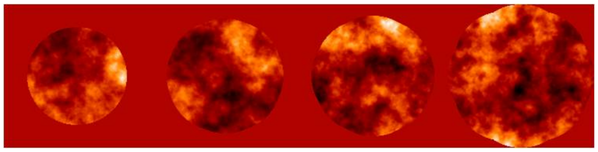

Fig. 3. Turbulent phase

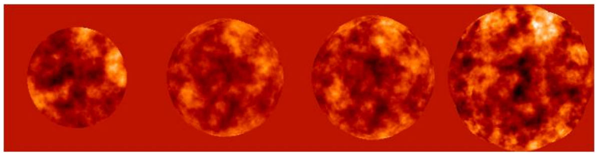

Fig. 4. estimated phase

Running on an octopro 2.1 GHZ and using the sparse End To End simulator we show in Figure 13 the result of the simulation for a different dimension of the telescope and where we reach the 42m for about 4min.

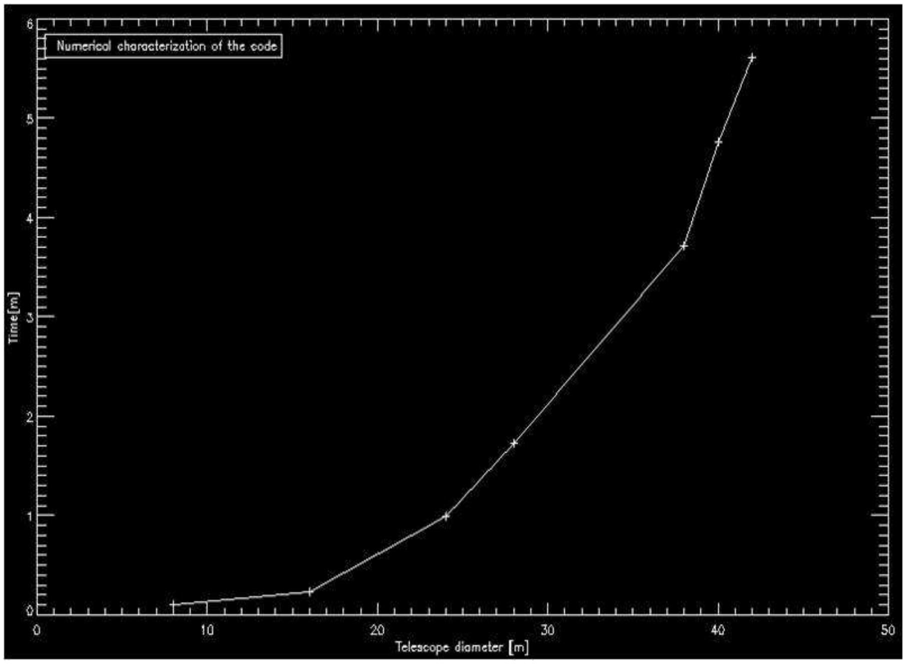

Fig. 5. Time characterization of the E2E sparse simulator

We demonstrate above the efficiency of the sparse matrix simulator for an AO system for the ELT, and as shown we are going 100 times fast then a CAOS E2E simulator running on the same octoprocessor.

6 Conclusion and perspective

We have presented an Adaptive Optics E2E simulator which includes a very fast wave front reconstruction which is dedicated for the Extremely Large Telescope.
Our code takes advantages of the SOY library, where we build the interaction and reconstruction matrix in a sparse format. Based on a script for solving linear systems by conjugate gradient with Jacobi preconditioner , our reconstruction matrix is computed very fast.
Moreover, this simulator is going 100 times faster then a present simulator running on the same octoprocessor. The objective of developing this code is to obtain an E2E simulator for wide field of view instruments for ELTs and more spcifically for an MOAO instrument such as Eagle on the E-ELT. The next step of our work, on which we are currently working to acheive this objective is the implementation of the laser guide stars and the wave front sensor such as Shack-Hartmann.

References

Carbillet, M., Vérinaud, C., Guarracino, M. et al. 2004, Proceedings of the SPIE, Volume 5490, 637

Carbillet, M., Vrinaud, C., Femenía, B. et al. 2005, MNRAS, 356, 1263

Rousset, G. 1999, in *Adaptive Optics in Astronomy*, F. Roddier (ed) (Cambridge: Cambridge University Press), p. 91