NEW CALIBRATION SINUSOIDAL TECNIQUE APPLIED TO *Large Binocular Telescope*

Francesca Pieralli, A.Puglisi, F.Quiros-Pacheco, S.Esposito

INAF – Osservatorio Astrofisico di Arcetri, Firenze, Italy

e-mail: pieralli@arcetri.astro.it

LARGE BINOCULAR TELESCOPE INSTRUMENT :

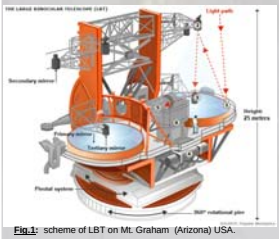
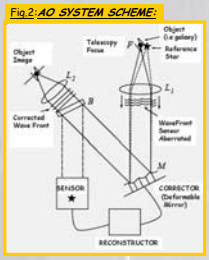


Fig.1: scheme of LBT on Mt. Graham (Arizona) USA.

The LBT has been designed to offer astronomers as much flexibility as possible. The two large mirrors can be used separately with different instruments above each. These are swung into position on gantries and allow different aspects of the same object to be measured simultaneously.
However, the light from each mirror can also be combined to make one high-resolution image. Here is how it works:
1. As the light enters the telescope and hits the huge mirrors - the largest ever made from a single piece of glass - it is deflected towards the secondary mirrors above.
2. Because the Earth's atmosphere distorts the light from stars, adaptive optics are used to correct the image. Moving magnets on the back of the secondary mirrors can change their shapes 1,000 times second.
3. The corrected light is deflected towards the centre of the telescope where one of various instruments combines the beams.
4. The dynamic balancing system compensates for movements of the telescope and helps it remain fixed on one spot in space.
5. The light can be used in different ways. The LBT interferometer (LBTI) can be used to reverse its phase, effectively cancelling the light from a bright star and allowing astronomers to look for faint, orbiting planets.
6. The interferometric camera is used to combine the light in phase, allowing high-resolution images to be taken. In this mode, the telescope has the equivalent sharpness of a 22.8m (75ft) instrument.

Fig.2: ***AO SYSTEM SCHEME:***



GOAL:
correcting the image on the focal plane

WHY:
teoretical performance: $\lambda / D = 0.025$"@1 μm
Average seeing : 1"
because of atmospheric turbolence!

AO system components:

-**Wavefront sensor**: detection of wavefront local slopes.

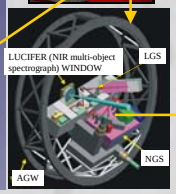
-**Wavefront reconstructor**: determines the mirror actuator commands to compensate for the wavefront slopes.

-**Corrector** (deformable) mirror.

Works in closed loop in order to have a fast tracking of continously changing atmospheric turbolence.

Fig.4: **AGW UNIT**
Acquisition **G**uiding & adaptive optics **W**avefront sensor

Fig.3: schematic design of LBT



Made in Arcetri Observatory (Florence,Italy)

Fig.5: WaveFrontSensor (**WFS**) BOARD

The AGW units are supported inside a circular structure bolted to the telescope derotator of the front bent Gregorian foci.
A foundamental part of the board is the pyramid ***wavefront sensor***, that has been designed and polished in Arcetri[1,2]

1

TWO PRINCIPAL ELEMENTS OF AO SYSTEM: WaveFrontSensor (WFS) and Deformable Secondary Mirror (DSM)

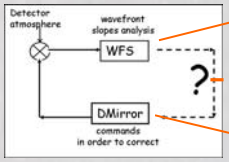


Fig.5: part of scheme of closed loop AO system

thanks to the pyramid sensor we can detect errors on the incoming wavefront

HOW TO LINK THESE TWO PIECES ?

The deformable mirror can compensate an arbitrary wavefront assuming an opposite shape, so that the result wavefront is flat.

After slopes calculation **we need a wavefront reconstruction** in order to connect the errors calculated by the sensor with the relative movement of the deformable mirror

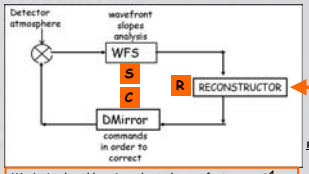


Fig 6: scheme of closed loop AO system

Works in closed loop in order to have a fast tracking of continously changing atmospheric turbolence.

So there is a **calibration procedure** in order to connect WFS board to deformable mirror, it's like to set a language between them.
Thanks to that, during the observation we can give realtime commands to the mirror to correct the incoming wavefront aberration.

→ATMOSPHERE DETECTION: **SENSOR ---------- > DM**
WE CAN CORRECT THE ABERRATION ON THE WAVEFRONT → **S * R = C**

WE NEED THE **INTERACTION MATRIX** IM IN ORDER TO FIND "R"
IM = R $^{-1}$ → **C * IM = S**

DEFORMABLE SECONDARY MIRROR — I_M → R — WAVEFRONT SENSOR

THAT CAN NOW COMUNICATE TOGETHER!

2

3

THERE IS A CLASSICAL CALIBRATION TECNIQUE: working in open loop we push and pull each single actuator of the deformable mirror one after the other, measure the corrisponding sensor vectors of the WFS, observing a reference source located in a focal plane in front of the DM. This can be a **problem** for high order AO system, like LBT with 672 DSM actuators, becouse we need a lot of time for each one Interaction matrix: i.e 20 seconds for eac mode, so for LBT 20*672=4 hours for all IM !!!

WE NEED NEW CALIBRATION TENIQUE[3,4,5]: SINUSOIDAL MODULATION TECNIQUE[6,7] APPLYIED TO LBT SYSTEM
The priciple is very sample: each mode applyed to DSM is modulated with by a sinusoidal signal, entering in to the loop AO correction all the signal are recorded by the WFS, and after is demodulated. So the demodulation is equivalent to a narrow nabd pass filter, witch is able, at the working frequency, to retrieve the modulate signal.

INTRODUCTION OF SINUSOIDAL SIGNAL : a frequency value for each mode

$C_1 * \sin_{(a)}$ ------ > S_1	*Sinusoidal signal with frequency a*
$C_j * \sin_{(b)}$ ------ > S_j	*Sinusoidal signal with frequency b*
$C_n * \sin_{(c)}$ ------ > S_n	*Sinusoidal signal with frequency c*
C_{Tot} ------ > S_{Tot}	*(Hp: mirror and sensor are linear devices)*

I CAN MEASURE MORE MODES at the same time!!!

1) Select a different frequency for each mode (no multiple frequency)
2) Modulate each command with a sinusoidal signal at that frequency
3) Sum all commands together
4) Apply the summed commands to the mirror and record sensor signals
5) Repeat steps 3 and 4 for each integration step

6) Demodulate the sensor signals with the different frequencies to recover the single modes applied.

GAIN WITH SINUSOIDAL MODULATION TECNIQUE :

Gain in time integration[7]!!!!
gain time proportional to the # modes applicated in a single measure
Ex: a matrix of 672 modes, with 10 sec integration for each mode: 2 h !!!
Using sinusoidal modulation tecnique, with 20 modes at the same time: 6 min !!!

Gain in S/N[7] !!
any noise at a different frequency from the one selected will be rejected by the demodulation

Gain[7]: with this tecnique it's possible to measure the **interaction matrix directly on sky**, using a star as reference source. AO loop will be closed so one has to select frequencies outside the loop correction bandwidth, in LBT case >40 Hz
Why: the complete system is measured instead of just a subset as in the laboratory

4

THIS NEW SINUSOIDAL CALIBRATION TECNIQUE FOR LBT WILL TEST IN THIS SUMMER IN ARCTERI TOWER USING AN ENVIROMENT SIMILAR TO THE TELESCOPE!

In the solar tower we can check the AO system all together: deformable mirror and pyramid wave front sensor at the same time and in the same working condition as at the telescope. The height of the tower is equal to the distance between DSM and its focus, on the top of it we have the hexapod system and DSM 672 actuators, the same that will go to the telescope, on the bottom of the tower there is the optical board with the pyramid wave front sensor.

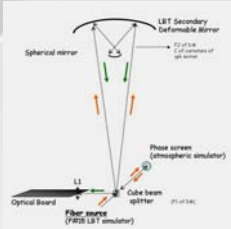


Fig 7 : on the left a picture of solar tower in Arcetri Observatory. In the center a schematic representation of the whole system into the tower. We used a phase screen, positioned on the incoming beam toward the secondary mirror, which introduces a turbulent wavefront that allow us to analyze the behavior of the whole adaptive system in a realistic condition. On the right an optical design of the LBT with the mirrors system.

Pre-test:
may and june 2008 --- > **simulations** of sinusoidal modulation technique applied to LBT system is work in progress in order to check the effect on SNR of changing the sinusoidal frequency and amplitude of the injected signal and modulate all the number of 672 modes. We work as in open as in close loop looking for the best LBT IM[6].

Results of simulations:
We'll be used to drive our tests in the tower.
Best calibration → best IM → best corrections of wavefront aberrations → *best SNR*!
We'll using this calibrationat at the telescope!

July-december 2008 --- >we'll check the whole LBT AO system, using a fiber source as a reference source.
It's a very important test: best complited set up system!!
*test with atmosphere simulated by the phase screen
*test with IR camera supplied by Bologna (chek the PSF value in K window)

LBT must have AO system, otherwise It doesn't exploit its full capability!!

Fig 8: shell of one of the primary mirror transported on Mount Grham.
AO group the will go to LBT in order to commission the AO system

i.e scientific application of LBT :

*LBTI → the first project in order to build LBT (bonocular telescope)
→ extrasolar planets
→ variable stars
→ supernovae research

*LUCIFER → will provide imaging, long-slit and multi-object spectroscopy, using 33 exchangeable masks.
→ IR ,9 -2.5 micron
→ 4*4 arcmin f.o.v
→ spectroscopy R: 10000-40000
→ high redshift objects (star forming galaxies, stellar absorption, line emitters)

REFERENCES:

1. S. Esposito, A. Tozzi, A. Puglisi, L. Fini, P. Stefanini, P. Salinari, D. Gallieni, and J. Storm, in Astronomical Adaptive Optics Systems and Applications. Edited by Tyson, Robert K.; Lloyd-Hart, Michael., SPIE Proc. 5169, pp. 149-158, Dec. 2003.
2. E. Diolaiti, A. Tozzi, R. Ragazzoni, D. Ferruzzi, E. Vernet-Viard, S. Esposito, J. Farinato, A. Ghedina, and A. Riccardi, in Adaptive Optical System Technologies II. Edited by Wizinowich, Peter L.; Bonaccini, Domenico, SPIE Proc. 4839, pp. 299-306, Feb.2003.
3. M. Kasper, E. Fedrigo, D. P. Looze, H. Bonnet, L. Ivanescu, and S. Oberti, Optical Society of America Journal A, 21, pp. 1004-1008, 2004
4. F. P. Wildi and G. Brusa, Advancements in Adaptive Optics, D. Bonaccini Calia, B. L. Ellerbroek, and R. Ragazzoni, eds., 5490, pp. 164-173, 2004
5. S. Oberti, R. Muradore, S. Esposito, R. Arsenault, E. Fedrigo, M. E. Kasper, J. Kolb, E. Marchetti, F. Quiros-Pacheco, and C. Soenke, in Advancements in Adaptive Optics, D. Bonaccini Calia, B. L. Ellerbroek, and R. Ragazzoni, eds., 6272, in publication 2006.
6. S. Esposito, A. Tozzi, A. Puglisi, E. Pinna, A. Riccardi, S. Busoni, L. Busoni, P. Stefanini, M. Xompero, D. Zanotti, and F. Pieralli, in *Advances in Adaptive Optics II*, B. L. Ellerbroek and D. Bonaccini Calia, eds., vol. 6272 of *Proc. SPIE*, July 2006.
7. S. Esposito, R. Tubbs, A. Puglisi, S. Oberti, A. Tozzi, M. Xompero, and D. Zanotti, in *Advances in Adaptive Optics II*, B. L. Ellerbroek and D. Bonaccini Calia, eds., vol. 6272 of *Proc. SPIE*, p. 62721C, July 2006
8. F.Pieralli, S.Esposito,A.Puglisi, F.Quiros-Pacheco, *"sinusoidal calibration tecnique for Large Binocular Telescope system"*, 2008 SPIE, submitted