PSF RECONSTRUCTION FOR ALTAIR AO SYSTEM ON GEMINI NORTH

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MOTIVATIONS AND OBJECTIVES

Jean-Pierre Veran method has been demonstrated successfully (1997) for curvature systems on PUEO at CFHT. The method has its own limitations and does not work well for noisy conditions, but for normal cases with bright to moderately bright NGS, its efficiency has been demonstrated. It appears though that JPV software was not maintained and not implemented as a service to the observer (Roland Bacon for instance was a user of PUEO, and really needed the PSF, but never got the PSF-R software working [pers. com.]).

Since 1997, several groups have adapted JPV method for SH-based systems, and even though it was demonstrated that it worked also for such systems (R. Weiss, ALFA system, and our own group on Altair lab measurements), there has always been a lack of human resources not only to finalize the developed PSF-R tools as a service to the observer, but also to get enough telescope/AO data to explore fully the limits of the method (ex: Florence Rigal, Groningen, was supposed to implement JPV method on MACAO for the VLT, but never got the telescope data she needed, and as she was also lacking AO expertise, the project failed, and it was said that PSF-R simply does not work). Fortunately, astronomers are smart, and always find solutions to go round this lack of knowledge of the AO-PSF. Also, as these AO-PSF (even with a limited degree of accuracy) are not available, nobody ask for them. On the other hand, if these PSF would be available, people would use them. Do HST users ignore the telescope PSF database?

On the long term, this situation is not acceptable. Even if for some science cases a lack of PSF knowledge is not an issue (as deconvolution gurus would say), **the risks of not being able to reduce properly complex AO systems data cannot be taken**, in regard to the astronomical costs of the future instruments for the 8-10 m class telescopes, and more importantly, for the ELTs. As an example, MUSE instrument for the VLT AO-Facility system requires the knowledge of the LTAO-PSF, or to say differently, MUSE science program cannot be done if the PSF is not known (Roland Bacon, MUSE PI, pers. com).

So, to summarize, my understanding is that currently there is a large diversity of opinions in the AO community, from people saying that PSF-R will never work, people saying that it is not needed, others who would like to have the PSF but find solutions to go round this, and people who just desperately need it. But as far as I know, JPV method, which works and is not terribly complex to implement, is available *nowhere* as a general service to the AO observer. We should change this as soon as possible: once it is implemented on a world class 8-10 m class instrument (SH-based AO), with lots of people using it, we can expect a change in the way people are seeing this, and possibly, it will also be easier to get money for PSF-R development on more complicated, multi-WFS & multi-DM systems. Finally, only by implementing JPV method will we be able to know its actual limits, and justify further research on improvements.

To reach this (rather political) objective, I would propose to finalize and implement, NOT as a research project but as an engineering project, the PSF-R tool (OPERA, see references below) that I have developed for ALTAIR. OPERA implements and adapts JPV method to SH systems, is written in IDL, and has been tested on turbulator data, during ALTAIR's tests in 2002 at HIA. Preliminary results were encouraging, even if we had a vibration (!) problem with the NIRI detector, and the wind velocity was set to … 100 m/s. As an example of PSF-R performance: system Strehl was 15%, OPERA PSF was at 13%. Not bad for a single test in such conditions. Unfortunately, we never got resources at HIA nor Gemini to test OPERA on sky data, and our group at HIA was certainly not pro-active enough. So the code is here, in my laptop, ready to get ALTAIR data, waiting for someone to finalize it with sky data.

OPERA has two parts: a core implementing JPV method, independently of the type of system, and interfaces for ALTAIR circular buffers data processing. To implement OPERA on another system, we need to rewrite the interfaces only. That was the idea when I built it. And it has a (primitive) documentation.

The work plan would be the following, <u>assuming that ALTAIR is in a state of readiness that will make the PSF-R project possible (no show stopper issues like … large vibrations)</u>

1. Take on-sky telemetry data from ALTAIR (see appendix) and test OPERA as it is right now,
2. Do the debugging (software & system),
3. Implement the final code as a service to ALTAIR users, after qualification,
4. Set up a procedure for maintenance, which is absolutely critical for the reasons indicated above.

I believe this project has relatively low development risks and potentially large scientific and "political" gains.

OUTCOME, DELIVERABLES

1. A PSF-R tool implemented on ALTAIR pipeline for automatic generation of AO PSF, attached to AO run data files, by default.
2. Code description and detailed documentation for AO engineers.

3. Documentation for users.

IMPORTANT REMARKS

- People that will do the work: Laurent Jolissaint (LJO); Julian Christou (JCH). This list will potentially evolve.
- Tasks list and duration are preliminary and will evolve with the definition of the project.
- Implementing OPERA on ALTAIR is the baseline. If not possible, a backup solution can be explored – Keck?
- During debugging stage, Laurent and Julian will need to spend a significant amount of time on the mountain at MK. The rest of the time, Laurent will work from Europe, as he cannot relocate himself to Hawaii for family and professional reasons.

ACTIONS, PEOPLE, TIME – <u>THIS IS PRELIMINARY & NEEDS TBC</u>

AI ID	Action	Who	Time
AI-01	Get back on OPERA (house keeping, run it on ALTAIR archive data). Can be done in parallel with AI-02.	LJO	2 weeks
AI-02	Prepare ALTAIR to get what we need as data (see list in the appendix).	LJO JCH +?	1 month
AI-03	Get on-sky AO data, first batch.	JCH LJO +?	1 week
AI-04	Testing OPERA on 1st batch of sky data.	LJO JCH	1 month
AI-05	System debugging – ALTAIR & OPERA.	LJO JCH +?	2 months
AI-06	2nd batch of OPERA tests on new data	LJO JCH	1 month
AI-07	Prepare OPERA to make it compatible with GEMINI observatory software standards	LJO	1 month
AI-08	Implement OPERA inside ALTAIR data pipeline	LJO JCH +?	1 month
AI-09	Testing final product, ensure that it delivers what was expected	LJO JCH	2 weeks
AI-10	Set-up a code maintenance procedure	LJO JCH	2 weeks
AI-11	Writing documentation	LJO JCH	1 month
	Provision for delays, vacations		1 month
	TOTAL REQUESTED TIME (approx.)		10 months

SCHEDULE

Starting January 2010 would increase our chances to show something interesting at the SPIE meeting in June 2010. Now, the readiness of ALTAIR is a large uncertainty, so we need to consider KO date t_0 as the time when ALTAIR is ready. Then,

t_0+1m : first batch of AO data available
t_0+2m : first test of OPERA done
t_0+4m : debugging of ALTAIR & OPERA done
t_0+5m : final tests of OPERA done
t_0+6m : OPERA made compatible with Gemini Observatory standards
t_0+7m : OPERA implemented into ALTAIR data pipeline
t_0+7.5m : demonstrating compatibilities of deliverable with specifications
t_0+8m : maintenance procedure defined and implemented
t_0+9m : documentation written.
t_0+10m: end of project.

RISKS & MITIGATIONS

ID	Risk	Possible causes	Mitigation
1	ALTAIR system failures	The project should not start if ALTAIR suffers from un-expected issues like significant vibrations, and heavy NCPA, for instance. That was one of the reasons for failures on other PSF-R projects.	Be sure the system is ready before project starts, or that system's failures are not show stoppers for the project.
2	Lack of reliable AO data	Unexpected failures during AO data acquisition. Bad communication between teams. The **main** cause of failures on previous project.	Maximize readiness of AO system. Organize efficient communication and data transfer link between observatory and OPERA team, with verification of compliance to data acquisition specifications.
3	Lack of expertise in AO, lack of support from observatory.	That was a source of failure on previous projects. Isolated, un-experienced PhD students w/o real support.	Hire experienced post-docs in AO. Have a group of AO gurus at reach. Europe, with ONERA people, is a good location for LJO.
4	Lack of telescope time	...	Prepare well in advance. Engineering time should be used.

5	Lack of support from astronomical & AO community	AO people are buy building systems, astronomers are busy doing their science, everyone expect that the other is going to ask/provide AO PSF.	Find a tiny minority of dreamers and do it w/o waiting for people to wake up ;)

PARTNERS & ROLE

People	Institution	Role in project
Claire Max + TBD	Center for Adaptive Optics	**Resources**, AO expertise
Julian Christou (Mark Chun ?)+TBD	GEMINI Observatories	**Resources**, **man-power**, AO expertise
Eline Tolstoy	Groningen University, NL	**Resources**, AO data reduction expertise
Laurent Jolissaint	Location TBD	**Man-power,** AO expertise

REFERENCES

<< OPERA, an Automatic PSF Reconstruction Software for Shack-Hartmann AO Systems: Application to Altair >>
L. Jolissaint, J.-P. Veran and J. Marino
SPIE Proceedings 5490, pp. 151-163, 2004

<< On-Line Long-Exposure Phase Diversity: a Powerful Tool for Sensing Quasi-Static Aberrations of Extreme Adaptive Optics Imaging Systems >>
Mugnier, L. M.; Sauvage, J.-F.; Fusco, T.; Cornia, A.; Dandy, S.
Optics Express, vol. 16, issue 22, p. 18406, October 2008

APPENDIX: ALTAIR data needed for PSF-R with OPERA

CIRCULAR BUFFERS

1. Commands to the DM's actuators: must be given in stroke amplitude [microns].
2. Modal gains: if modal optimization implemented, otherwise give the static loop gain for each modes.
3. WFS measurements: we need the raw ADU for each quadrant on each sub-aperture.
4. Centroid gains, i.e. from 4-Quadrant output to actual slopes.

MATRICES

1. Command matrix. Specifically: slopes to mirror modes, invisible modes taken into account (set to 0).
2. Actuators to modes matrix: it should be possible to translate the units of the matrix from the working units - volts, whatever - to linear units (microns, in general). So, conversion factors are needed.
3. Gamma_ij matrix: Mirror modes *coefficients* covariance matrix for a Kolmogorov (or Von Karman) turbulent flow. In other words, the translation of Noll's covariance matrix given for Zernike modes in the basis of DM modes. First mode is in principle tip-tilt, and [i,j] indexes run from 1 to the last mirror mode N.
4. Uij functions: This object is a four dimensions array. Each [i,j] component gives the spatial correlation (a 2D object) of the mirror modes i and j. As it is a huge array - can take up to several Gbytes - it is better not to send it with the other system's buffers or matrices, but rather send the mirror modes matrices, from which the Uij's can be calculated on-line, when needed.

ACTUATORS & APERTURES "MASKS"

1. maskServActInRealAct
2. maskValidSubAp

IMAGES

1. WFS CCD offset matrix: CCD output with 0 sec exposure time and no light.
2. WFS CCD dark bias: CCD output with no light at the input but with the working exposure time.
3. An AO corrected PSF: point an un-resolved star, do the correction, register the star image and the AO loop commands. From this PSF, we will determine the telescope intrinsic PSF, removing the atm+AO contribution, based on the reconstructed AO PSF. As the telescope PSF is evolving with a much slower time scale than the seeing, this estimated telescope PSF can be used as the static PSF during all subsequent AO runs. Note: another and potentially more efficient method can be used: phase diversity on long exposure AO PSF. See Mugnier et al. Optics Express 2008.

SCALAR DATA

1. Electrons to ADU WFS CCD gain
2. CCD read noise [e/px]
3. WFS sampling temporal frequency
4. Loop time lag

5. Science filter wavelength and bandwidth, or filter transmission curve
6. Actuator pitch, as seen from the telescope primary mirror
7. Telescope primary mirror diameter and central obscuration ratio
8. Science camera pixel size [asec/px]
9. All rotation/reflection geometric angles to be able to rotate/inverse images, from the AO system reference focal plane to the science camera focal plane.