Fast correction in adaptive optical system using block control

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Purpose

We propose to take advantage of the sparse structure of the control matrix in adaptive optical systems in order to allow the acceleration of the control loop in real time wavefront correction. The idea is using the local behavior of the influence functions of the deformable mirror to convert the control matrix into a tridiagonal block structure, allowing parallel computation of different zones of the mirror. The efficiency of proposed technique relative to classical methods grows with number of actuators.

Methods

Most deformable mirrors (DM) have a certain degree of locality in their response functions, when each single actuator influences a corresponding area on the pupil affecting a limited number of Shack-Hartmann WFS nodes relative to their total number all over the pupil. Poke matrix of a DM with significant response functions locality would have a number of zero and quasi-zero coefficients, having thus a sparse structure. This is an advantage, as operations on sparse matrices may be considerably faster compared to fully populated matrices of the same order. However, the pseudo-inverse matrix does not inherit the sparseness of original matrix in the general case. Thus, classical least square solution takes no advantage of initial poke matrix sparseness, having a total amount of control calculations proportional to the square of the number of actuators (on the assumption of a given nodes/actuator density in the pupil). This problem is becoming more and more important due to the growing number of actuators in modern mirrors for extremely large telescopes [1]. Iterative methods such as conjugate gradient [2] have been proposed to reduce calculation volume for large mirrors real-time control [3].

In our method, a reorganization of the control matrix is done in a form where the most valuable coefficients become concentrated near the matrix diagonal, which is left arranged as a block matrix with tridiagonal structure. This way it is possible to parallelize control signal calculations while maintaining a good accuracy, enhancing the speed of the control loop. The degree of locality in the response functions, and the number of elements in the matrix define the gain in calculation efficiency for an adaptive system under this approach.

Results

A Von Karman atmospheric turbulence model was used for dynamic aberration simulation [4]. The poke matrix was built using an available commercial 37-channel piezoelectric deformable mirror combined with a Shack-Hartmann wavefront sensor with 127 apertures. The optical performance (residual error in slopes data for a correction cycle sequence) is presented in Fig.1 for a number of correction methods. Initial RMS aberration due to turbulence is shown as a solid line. Residual RMS error is then calculated for classical least squares solution using singular value decomposition (green, long dash), conjugate gradient method (red, short dash), preconditioned conjugate gradient method (blue, dot-dashed) and block control method (purple, cross markers). Both least squares and conjugate gradient method use fully populated matrices. Preconditioned conjugate gradient and block control methods use truncated poke matrices.

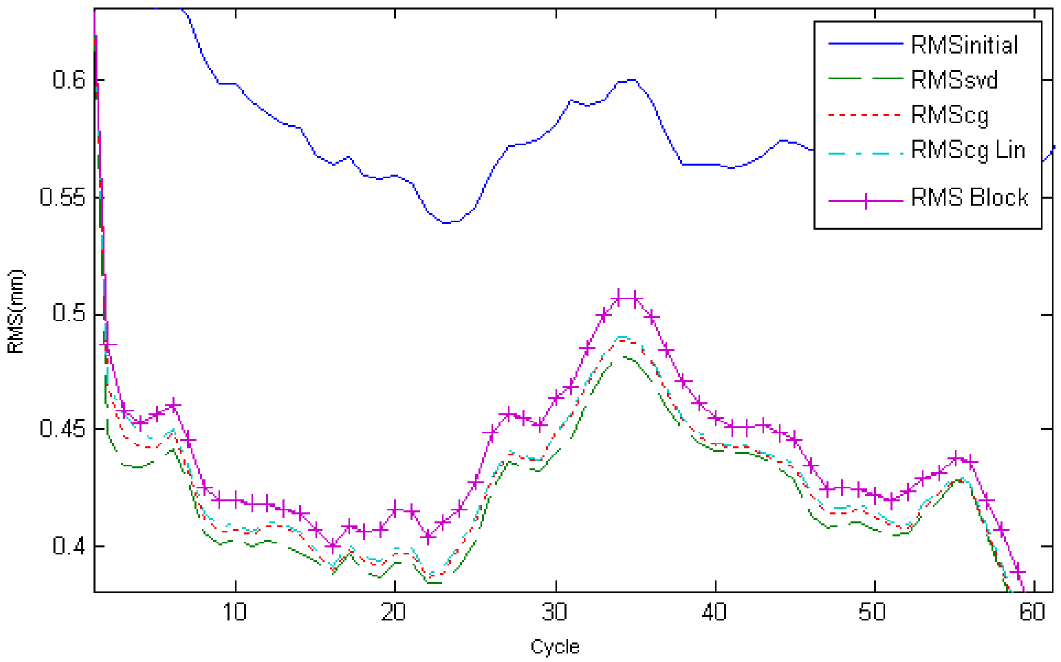

Fig. 2. Numerical simulation for performance (residual slopes RMS against compensation cycles)

Results show the closeness of all involved solutions in terms of RMS values. However, one of the methods is suitable for direct parallelization though the subdivision of the control matrix in blocks. The degree of block division will be more relevant as the number of actuators in the mirror and the sparseness of the matrix grow. Experimental evaluation of the proposed method is currently in progress.

Conclusions

Block control is proposed as a method for cutting down bulky calculations in a control loop, reducing computation time at the expense of a reasonable residual error rise. The method is based on taking advantage of the sparseness of the control matrix. The performance gain for dynamic correction depends on the degree of locality of adaptive system and the speed of aberration.

References

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