ARCETRI
TECHNICAL REPORT

Doc.No : 1/2012
Version : 2
Date : 15 Apr 2012

Slaving actuators with voice-coil adaptive mirrors

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ABSTRACT

Adaptive mirrors based on voice-coil technology have force actuators with an internal metrology to close a local loop for controlling its shape in position. When actuators are requested to be slave control matrices have to be re-computed. The report describes the algorithms to re-compute the relevant matrixes for controlling of the mirror without the need of recalibration. This is related in particular to MMT, LBT, Magellan, VLT, EELT and GMT adaptive mirrors that use the voice-coil technology. The technique is successfully used in practice with LBT adaptive secondary mirror units.

Modification Record

Version	Date	Author	Section/Paragraph affected	Reason/Remarks
1	13 Jan 2012	A. Riccardi		First release of the document
2	15 Apr 2012	A. Riccardi	All	Cross references to Eqs. fixed
			Sec.3	Eq.(5) and (7) missing term added

Abbreviations, acronyms and symbols

Symbol	Description
EELT	European Extremely Large Telescope
FF	Feed-Forward
GMT	Giant Magellan Telescope
IF	Interaction Function
IM	Interaction Matrix
LBT	Large Binocular Telescope
VLT	Very Large Telescope

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1 Introduction

Adaptive mirrors based on voice-coil technology have force actuators with an internal metrology to close a local loop for controlling its shape in position. This technology is already in use on 8m class telescope like LBT [1] and is foreseen for other telescope with the same class like VLT [2] and on Extremely Large Telescopes like EELT (M4) [3] and GMT (M2) [4].

When actuators are requested to be slave or disabled, control matrices have to be re-computed in order to avoid a re-calibration of the system. A key matrix for the functioning of this kind of mirrors is the Feed-Forward (FF) matrix [5], i.e. the matrix relating the force requested to apply a given shape. This matrix can be associated to the stiffness matrix of the deformable shell. Let's distinguish two cases as following:

- Disabling actuators: this is the case when an actuator stops working for a failure (on the force driver or the position sensor) and its internal control loop is disabled. It cannot apply the FF force and the relative matrix has to be recomputed;
- Actuators outside the optical pupil cannot be disabled, they are clustered and disabling them would give a severe problem in mirror shell control. The control bandwidth is related to the damping per unit mass [1] and disabling actuators requires their mass to be controlled by the neighbors reducing their controllability. That is acceptable per sparse disabled actuators, but it is not acceptable for clustered ones. Those actuators require to be kept in local closed loop, so a position command is required for them. Because the actuators are outside the optical pupil, their position command has to be extrapolated from the commands of the other actuators (for instance provided by the adaptive optical loop).

2 Relevant matrixes and their definitions

The matrixes that are involved in the re-computation are defined in the following sub-section.

2.1 The Feed-Forward matrix K

The FF matrix $\boldsymbol{K}$ relates the force vector $\boldsymbol{f}$ that is needed to apply a corresponding position command $\boldsymbol{p}$ as follows

(1) $$\boldsymbol{f} = \boldsymbol{K}\boldsymbol{p}\,.$$

The FF matrix is defined for enabled actuators having both force driver and position sensor properly working.

2.2 The Influence Function Matrix M

The IF matrix $\boldsymbol{M}$ relates the position command vector $\boldsymbol{p}$ with the shape of the optical surface of the mirror $\boldsymbol{w}$ as follows

(2) $$\boldsymbol{w} = \boldsymbol{M}\boldsymbol{p}\,.$$

2.3 The Interaction matrix D

The IM $\boldsymbol{D}$ relates the Wavefront Sensor signal vector $\boldsymbol{s}$ with mirror position vector $\boldsymbol{p}$ as follows

(3) $$\boldsymbol{s} = \boldsymbol{D}\boldsymbol{p}$$

3 Disabling or slaving actuators in the FF matrix

Let us consider the case a subset of actuators has to be disabled because no longer able to apply force or constrained for any reason to not apply force. In order to simplify notation, we will suppose the first n actuators to keep in the list of enabled actuators (identified by index i) and the last m actuators to move out of that list identified by index o). $N = n + m$ is the total number of degrees of freedom of the mirror. Eq. (1) can be re-written as

(4) $$\begin{pmatrix}\boldsymbol{f_i}\\ \boldsymbol{f_o}\end{pmatrix} = \begin{pmatrix}\boldsymbol{K_{ii}} & \boldsymbol{K_{io}}\\ \boldsymbol{K_{oi}} & \boldsymbol{K_{oo}}\end{pmatrix}\begin{pmatrix}\boldsymbol{p_i}\\ \boldsymbol{p_o}\end{pmatrix}$$

Because the disabled actuators do not apply force, for them $\boldsymbol{f_o} = 0$, while the corresponding position $\boldsymbol{p_o}$ is unknown because without control. From Eq. (4) we have

(5) $$\boldsymbol{f_i} = (\boldsymbol{K_{ii}} - \boldsymbol{K_{io}}\,\boldsymbol{K_{oo}^{-1}}\boldsymbol{K_{oi}})\boldsymbol{p_i}$$

and

(6) $\boldsymbol{p_o} = -\boldsymbol{K_{oo}^{-1}K_{oi}p_i}$

From Eq. (5) we can define

(7) $\boldsymbol{K'} = \boldsymbol{K_{ii}} - \boldsymbol{K_{io}}\,\boldsymbol{K_{oo}^{-1}K_{oi}}$

as the new FF matrix restricted to the set of enabled actuators.

In case the actuators were slaved and not disabled, we have to send a command to them requiring their force to be kept low. When a vector $\boldsymbol{p_i}$ of position command is applied to the master actuators, the command $\boldsymbol{p_o}$ to send to the slave set of actuators is given by Eq. (6), assuring zero force to them.

4 Influence Function matrix in case of disabled or slave actuators

Combining Eq. (2) and (6) we have

(8) $\boldsymbol{w} = \boldsymbol{Mp} = (\boldsymbol{M_i} \quad \boldsymbol{M_o})\begin{pmatrix}\boldsymbol{p_i}\\ \boldsymbol{p_o}\end{pmatrix} = (\boldsymbol{M_i} - \boldsymbol{M_o K_{oo}^{-1} K_{oi}})\boldsymbol{p_i} = \boldsymbol{M'p_i}\,.$

where

(9) $\boldsymbol{M'} = (\boldsymbol{M_i} - \boldsymbol{M_o K_{oo}^{-1} K_{oi}})\,.$

represents the new IF matrix restricted to the set of master actuators.

It has to be noted that in order to obtain the new IF matrix, the IFs of all the actuators are required. In case a modal IM has been calibrated with a number of modes that is less than the total number of actuators, that information is NOT sufficient to re-compute the IF matrix. An initial calibration of all *N* zonal IFs or, equivalently, the full set of *N* linearly independed modes is required, even if a limited number of modes is used for closing the optical loop.

5 Interaction Matrix in case of disabled actuators

Combining Eq. (3) and (6) we have

(10) $\boldsymbol{s} = \boldsymbol{Dp} = (\boldsymbol{D_i} \quad \boldsymbol{D_o})\begin{pmatrix}\boldsymbol{p_i}\\ \boldsymbol{p_o}\end{pmatrix} = (\boldsymbol{D_i} - \boldsymbol{D_o K_{oo}^{-1} K_{oi}})\boldsymbol{p_i} = \boldsymbol{D'p_i}\,.$

where

(11) $\boldsymbol{D'} = (\boldsymbol{D_i} - \boldsymbol{D_o K_{oo}^{-1} K_{oi}})\,.$

represents the new IM restricted to the set of master actuators.

6 Conclusions

The formulas to compute FF, IF and Interaction matrixes in case of slave or disabling actuators have been reported, see Eq. (7), (9) and (11) respectively. The formula for computing the position commands to send to the slave actuators starting from the knowledge of the commands to the master actuators is also reported, see Eq. (6).

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