Summary of WFPC2 AFM and POMM Actuation Algorithm.

Chris Burrows Nov 18 1992

This note is to summarize part of the algorithms to be implemented in the ground system in order to control the WFPC2 actuated fold and pickoff mirrors. Each AFM actuator consists of two independently commandable segments, each camera has three actuators arranged roughly in an equilateral triangle, and there are three cameras with AFM. The actuators are arranged and numbered in a manner that rotates by 90 degrees between adjacent cameras, so that the nominal conversion to AFM tilt in detector coordinates (CCD rows and columns projected back optically to the AFM) is the same in all cameras. The one pickoff mirror mechanism is controlled around two axes of tilt, and the transformation of this tilt to the detector frame is dependent on the camera in use. Commanding for the pickoff mirror is discussed separately at the end of this note.

The cameras that contain AFM are PC1, WF3 and WF4 which we refer to as c=1,3 and 4 respectively. In a given camera, the segments are numbered s=1...6, with s=1 and s=2 being part of actuator 1, s=3 and s=4 belong to actuator 2, and s=4 and s=5 being part of actuator 3. In summary the chain of transformations is as follows. *A discussion of the inverse transformation which is necessary for commanding from desired pupil shear, or mirror tilts follows each step in italics.*

1. Data numbers (command units) are converted linearly to volts on the commanded segment, with coefficients that depend on the segment used:

$$V(c,s) = M(c,s)\ DN(c,s) + B(c,s)$$

The arrays M and B are given on page 11 of the Trauger/Moody memo. I can provide them as a machine readable ASCII table on request. Note that DN is in the range 0 to 255 inclusive and that M is close to 0.347, while B is close to zero. The maximum voltage on any segment is 90 volts.

As this is a linear transformation, inverting it is trivial.

2. Volts on each segment are converted to a tilt vector on the corresponding mirror. The temperature of the bench should be set as T=12 degrees, then the following formulas used to set two coefficients (which are independent of the segment being used):

$$b_1 = (4307. - 185.7T + 2.985T^2) / 10^7$$
$$b_2 = (-2491. - 161.0T - 3.324T^2) / 10^{11}$$

The magnitude of the tilt in microradians is computed as follows:

$$tilt(c,s) = scale(c,s)(b_1 V(c,s)^2 + b_2 V(c,s)^4)$$

where the scale array is given on pages 15 to 16 of the Trauger/Moody memo. Segment numbers 7, 8 and 9, in their table which correspond to individual actuators 1, 2 and 3 (average of two segments), and not real individual segments are ignored in this step. JPL is looking into the reason why the entry for 'segment' 7 (ie actuator 1) is not the sum of the entries for segments 1 and 2, as this algorithm would predict. scale(c,s) is in the range 500 to 570 microradians.

This step is inverted (given T and the tilt), by solving the above equation viewed as a quadratic in V^2, and taking the positive square root of the positive root.

$$V(c,s) = \sqrt{(b_1 - \sqrt{b_1^2 + 4b_2 tilt(c,s) / scale(c,s)}) / (2b_2)}$$

3. The tilt is then projected onto orthogonal coordinates with the direction cosines l(c,a) and m(c,a) given in the arrays part_x_tab and part_y_tab which are given in the same place in the Trauger/Moody memo. We use the measured average direction cosines for the relevant segment **pair** *(in order to make the transformation easy to invert).*

$$tilt_x(c,s) = l(c,a) * tilt(c,s)$$
$$tilt_y(c,s) = m(c,a) * tilt(c,s)$$

where a is the actuator number corresponding to segment s. l(c,a) is roughly (sin(300),sin(60),sin(180)) for a=1,2 and 3, independent of the chip number, while m(c,a) is roughly the same with cosines. l(c,a) and m(c,a) for a=1,2 and 3 correspond to part_x_tab and part_y_tab with segment indices 7, 8 and 9 respectively.

This step individually is inverted by noting that the total tilt on a given actuator is the rss of the tilt components on that actuator, and using the fact that the tilt must be positive.

$$tilt(c,s) = \sqrt{tilt_x(c,s)^2 + tilt_y(c,s)^2}$$

but normally it is inverted in conjunction with step 4 that follows.

4. The tilt vectors for all segments are added for each mirror:

$$tilt_x(c) = tilt_x(c,1) + tilt_x(c,2) + ... + tilt_x(c,6)$$
$$tilt_y(c) = tilt_y(c,1) + tilt_y(c,2) + ... + tilt_y(c,6)$$

This step is uniquely invertable, provided that one pair of segments is constrained to have zero tilt, and the tilts on the other two actuators are divided in a fixed proportion between their segment pairs. Algorithmically, the simplest approach is to try omitting each actuator in turn. For only one pair of actuators (a1, a2) picked from the set (1,2), (2,3) and (3,1), will the following equations give positive tilts.

$$tilt(c,a1) = (m(c,a2)tilt_x(c) - l(c,a2)tilt_y(c)) / (l(c,a1)m(c,a2) - m(c,a1)l(c,a2))$$
$$tilt(c,a2) = (m(c,a1)tilt_x(c) - l(c,a1)tilt_y(c)) / (l(c,a2)m(c,a1) - m(c,a2)l(c,a1))$$

then this tilt can be divided between the corresponding segments.

$$tilt(c,s1) = \alpha(c,a)tilt(c,a)$$
$$tilt(c,s2) = (1 - \alpha(c,a))tilt(c,a)$$

where s1 and s2 make up actuator a. The constants in this transformation are initially set to 0.5 for all actuators and channels. The above equation applied twice gives all the input segment tilts needed for step 3.

5. The total tilt vectors are then converted to detector coordinates, and arcseconds. The tilt vector in arcseconds in detector coordinates is used in the proposal. The coordinate system used in step 3 is nominally at 45 degrees to the nominal rows/columns of the CCD, but there may be a chip dependent rotation correction, so we refer to this angle as R_c (45 degrees in initial implementation).

$$prop_x(c) = 0.206265(\cos(R_c)\ tilt_x(c) - \sin(R_c)\ tilt_y(c))$$
$$prop_y(c) = 0.206265(\sin(R_c)\ tilt_x(c) + \cos(R_c)\ tilt_y(c))$$

The inverse transformation is:

$$tilt_x(c) = (\cos(R_c)\ prop_x(c) + \sin(R_c)\ prop_y(c)) / 0.206265$$
$$tilt_y(c) = (-\sin(R_c)\ prop_x(c) + \cos(R_c)\ prop_y(c)) / 0.206265$$

6. The AFM tilts can now be converted to image motion and pupil shear.

$$columns_change(c) = 0.004326\ F\ prop_x(c)$$
$$rows_change(c) = 0.004326\ F\ prop_y(c)$$

Where F is 28.5 for the PC1 camera and 12.9 for the WF3 and WF4 cameras, and

$$pupil_x_percent(c) = 0.02327\ prop_x(c)$$
$$pupil_y_percent(c) = 0.02327\ prop_y(c)$$

Conversely, one can convert a desired pupil shear, tilt or image motion back into command units. The transformation is uniquely invertable provided that one pair of segments is required to be at zero volts (not necessarily zero DN), and the proportion of the strain between each pair of segments is specified.
(initially as equal).

The pickoff mirror mechanism (POMM) is commanded as follows. The proposal instructions are written so that POMM tilts are specified in arcseconds in the WF2

detector frame. For a given camera c (=1,2,3 or 4) the rotation to the pickoff mirror coordinate system in degrees is R(c)=135-90c. In the case of WF2, R(2)=-45 degrees. Given commanded steps x_pomm_steps and y_pomm_steps, the corresponding x and y tilts on the mirror in arcseconds in detector coordinates are:

$$x_pomm_as(c) = 12(\cos(R(c))\ x_pomm_steps - 0.682\ \sin(R(c))\ y_pomm_steps)$$
$$y_pomm_as(c) = 12(\sin(R(c))\ x_pomm_steps + 0.682\ \cos(R(c))\ y_pomm_steps)$$

This equation is invertable in exactly the same way as the equations in step 5 above for the AFM.

$$x_pomm_steps = (\cos(R(c))\ x_pomm_as + \sin(R(c))\ y_pomm_as) / 12$$
$$y_pomm_steps = (-\sin(R(c))\ x_pomm_as + \cos(R(c))\ y_pomm_as) / (12 * 0.682)$$

These quantities convert into pupil shear as follows:

$$pupil_x_percent(c) = 0.27924\ x_pomm_as(c) / 12$$
$$pupil_y_percent(c) = 0.27924\ y_pomm_as(c) / 12$$

, and image motion as follows:

$$columns_change(c) = 0.20426\ F\ x_pomm_as(c) / 12$$
$$rows_change(c) = 0.20426\ F\ y_pomm_as(c) / 12$$