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Geometrical transforms for NIRSpec target acquisition

Abstract:

In this note we describe the geometrical transforms and the algorithm to be used to compute the sky coordinates of a given point in the NIRSpec focal plane, in the context of NIRSpec on-board target acquisition operations.

1 INTRODUCTION

As outlined in the NIRSpec Operations Concept Document (Boeker 2012), the purpose of the NIRSpec target acquisition (TA) procedure is to fine-tune the JWST pointing such that a given set of astronomical targets is imaged precisely onto the intended apertures. To compute this small pointing correction after the telescope main slew, NIRSpec on-board software must autonomously derive the *actual* telescope pointing in the sky, using a set of bright reference stars imaged onto NIRSpec detectors in dedicated short exposures (the acquisition images). During the TA procedure, the reference stars locations on the NIRSpec detectors are initially measured in the pixel coordinates of an individual detector array (SCA hereafter) and must be transformed by the on-board software into the undistorted, tangential coordinate system on the sky, before they can be compared to the desired ideal positions. This coordinate transformation requires precise knowledge of the combined distortion effects of NIRSpec and the Optical Telescope Element (OTE), as well as the actual tilt of the imaging mirror in NIRSpec Grating Wheel Assembly (GWA).
The purpose of this document is to describe the geometrical transforms that need to be applied to a given coordinate pair in one of the two NIRSpec detector arrays (identified here as SCA491 and SCA492) to compute its corresponding sky coordinates and to detail the necessary computational steps. Note that the sky coordinates here are given in the OTE object space angular coordinate system (i.e. V2,V3) specified in the JWST/ISIM NIRSpec Interface Control Document (Cole 2003). The geometrical transforms are based on the NIRSpec para-

metric model described in Giardino (2013), but the transforms presented here have been derived specifically for TA operations, with the aim of minimizing the number of on-board computations.

2 TA TRANSFORMS AND REFERENCE FILES

The essential steps to compute the OTE position of a point in NIRSpec detectors are the following.

- Transform the point xy-coordinates in pixel (in SCA491 or SCA492) to its angular coordinates at the GWA pupil plane
- Compute the difference between the mirror angle and its reference angle in the GWA, apply rotation around this incremental angle for the incoming ray, reflection at mirror, and inverse rotation around incremental angle for the exiting ray
- Transform angular coordinates of exiting ray at the GWA to its OTE coordinates

It is foreseen that TA will be executed with one of three different filters: F110W, 140X and CLEAR, therefore a total of 5 coordinate transforms needs to be available on board:

- SCA491 to GWA pupil plane
- SCA492 to GWA pupil plane
- GWA pupil plane to OTE for F110W
- GWA pupil plane to OTE for F140X
- GWA pupil plane to OTE for CLEAR

Together with this document we provide a total of seven reference files. Five reference files have extensions `.pcf` and contain the parameters for the 5 coordinate transforms listed above. The other two reference files have extension `.gtp` and contain the coefficients to convert the mirror sensor reading into the mirror tilt angle. The file format of both file types are detailed in the NIRSpec parametric model Interface Control Document (Giardino et al. 2013).
The names of the files and a summary of their content are listed in Table 1.

Table 1: Names of the reference files containing the parameters necessary to perform NIRSpec TA calculations.

N.	Name	Content
1	`delivery_SCA491toGWA.pcf`	Polynomial coefficients of coordinate transform from SCA491 to mirror
2	`delivery_SCA492toGWA.pcf`	Polynomial coefficients of coordinate transform from SCA492 to mirror
3	`delivery_F110W_GWA2OTE.pcf`	Polynomial coefficients of coordinate transform from mirror to OTE for F110W filter
4	`delivery_F140X_GWA2OTE.pcf`	Polynomial coefficients of coordinate transform from mirror to OTE for F140X filter
5	`delivery_CLEAR_GWA2OTE.pcf`	Polynomial coefficients of coordinate transform from mirror to OTE for CLEAR filter
6	`disperser_MIRROR_TiltX.gtp`	Coefficients to convert mirror sensor reading in y-direction to tilt angle in x-direction
7	`disperser_MIRROR_TiltY.gtp`	Coefficients to convert mirror sensor reading in x-direction to tilt angle in y-direction

3 COMPUTATIONAL STEPS

All the coordinate transforms, from SCA491 or SCA492 to the mirror, or from the mirror to the OTE (for each filter), have been parameterized using fifth order polynomials in X and Y. The coefficients are wavelength independent for the two transforms from SCA491 or SCA492 to the GWA plane. The transforms from the GWA to OTE are in general wavelength dependent, but, for the purpose of TA, the coefficients provided here have been derived for the center wavelength of each filter and can be directly applied to an exiting ray in the GWA plane, without knowledge of its wavelength.
So, given a point with x, y coordinates in the input plane (e.g SCA491), its coordinates in the output plane (e.g. the GWA pupil plane) will be given by:

$$x_{out} = P_x(x,y) = \sum_{i=0}^{5}\sum_{j=0}^{5-i} a_{ij}^{x} x^i y^j$$

$$y_{out} = P_y(x,y) = \sum_{i=0}^{5}\sum_{j=0}^{5-i} a_{ij}^{y} x^i y^j \tag{1}$$

A fifth order polynomial in x and y is parameterized by 21 coefficients. For each coordinate transforms 42 coefficients are provided for P_x and P_y separately in each `.pcf` file, but only the first 21 of these are different from zero and should be used for the transform[1]. The coefficients

[1]The number of 42 coefficients reflects the fact that in NIRSpec parametric model the transforms have a linear

for $P_x(x,y)$ and $P_y(x,y)$ are listed in the `.pcf` files under keywords `xForwardCoefficients` and `yForwardCoefficients`, respectively. The files provide the coefficients for the backward transforms as well but, for the purpose of TA, these can be ignored.
The transforms from SCA to GWA encode a transform between a position in one of NIRSpec detectors in pixel units to the angular position of the ray at the mirror expressed in `cosines` (number unit). The transforms from GWA to OTE go from angular position of the ray at the mirror also expressed in `cosines` to position in the OTE object space angular coordinates (V2,V3) expressed in degrees.

When computing the OTE position of a point in one of the two SCAs, the difference between the mirror angle for the given exposure and the reference angle at which the coordinate transforms were derived needs to be calculated. This requires reading from the exposure FITS header the values of keywords `GWA_XTIL` and `GWA_YTIL` which provide the sensor reading for the GWA tilt angle in the X and Y directions. For this computation one then needs to know the value of the sensor reading for the reference transform and the coefficients of the linear dependency between the sensor reading and the mirror tilt angle. These parameters are stored in files `disperser_MIRROR_TiltX.gtp` and `disperser_MIRROR_TiltY.gtp`, for the X and Y direction respectively. The reference sensor reading value is given under keyword `Zeroreadings` and we shall identify the value stored in `disperser_MIRROR_TiltX.gtp` as r_0^x and the value stored in `disperser_MIRROR_TiltY.gtp` as r_0^y. The slope of the linear relation between sensor reading and mirror tilt angle is given under keyword `CoeffsTemperature00` (first value of the two provided) and we shall identify the value stored in `disperser_MIRROR_TiltX.gtp` as A_X and that stored in `disperser_MIRROR_Tilt.gtp` as A_Y. Given these parameters, the mirror tilt angles in the x and y directions are given by:

$$\delta\theta_x = 0.5 A_X(\texttt{GWA\_YTIL} - r_0^x)$$

$$\delta\theta_y = 0.5 A_Y(\texttt{GWA\_XTIL} - r_0^y) \tag{2}$$

Since the units of the A coefficients are arcsec/mV, before proceeding, the angles $\delta\theta_x$ and $\delta\theta_y$ have to be converted from arcsec to radians.

Having computed the mirror angle difference with respect to the reference transform (in radians), we are now ready to perform the full computation of the sky position of a point in one of the SCA, following the steps below.

- Transform point xy-coordinate in pixel at the SCA to angular position at the GWA, $x_{\rm gwa}, y_{\rm gwa}$, using Eq. 1 with the parameters provided in `delivery_SCA491toGWA.pcf` or `delivery_SCA492toGWA.pcf`
- Compute the `direction cosines` of $x_{\rm gwa}, y_{\rm gwa}$:

dependency on wavelength, so that in general 21×2 coefficients are needed

$$|v| = \sqrt{1 + x_{\mathrm{gwa}}^2 + y_{\mathrm{gwa}}^2}$$

$$\begin{aligned} x_0 &= x_{\mathrm{gwa}}/|v| \\ y_0 &= y_{\mathrm{gwa}}/|v| \\ z_0 &= 1/|v| \end{aligned}$$

- Rotate the direction cosines of point at GWA pupil plane to the mirror reference system (i.e. a Cartesian system with z-axis aligned to the mirror normal) using the small angle approximation and perform reflection:

$$\begin{aligned} x_1 &= -(x_0 - \delta\theta_y \sqrt{1 - x_0^2 - (y_0 + \delta\theta_x z_0)^2}) \\ y_1 &= -(y_0 + \delta\theta_x z_0) \\ z_1 &= \sqrt{1 - x_1^2 - y_1^2} \end{aligned}$$

- Rotate reflected ray back to reference GWA coordinate system (again in the small angle approximation). First with an inverse rotation around the y-axis:

$$\begin{aligned} x_2 &= x_1 + \delta\theta_y z_1 \\ y_2 &= y_1 \\ z_2 &= \sqrt{1 - x_2^2 - y_2^2} \end{aligned}$$

  and then with an inverse rotation around the x-axis:

$$\begin{aligned} x_3 &= x_2 \\ y_3 &= y_2 - \delta\theta_x z_2 \\ z_3 &= \sqrt{1 - x_3^2 - y_3^2} \end{aligned}$$

- Compute `cosines` from `direction cosines`:

$$\begin{aligned} x'_{\mathrm{gwa}} &= x_3/z_3 \\ y'_{\mathrm{gwa}} &= y_3/z_3 \end{aligned}$$

- Transform cosines coordinate of point at the GWA, $x'_{\rm gwa}, y'_{\rm gwa}$, to its angular position at the OTE (V2, V3), using Eq. 1 with the parameters provided in `delivery_F110W_GWAin2OTE.pcf` or `delivery_F140X_GWAin2OTE.pcf`, or `delivery_CLEAR_GWAin2OTE.pcf`, according to the filter which is being used.

REFERENCES

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