TITLE: FOC image correction I: a new RSDP pipeline.

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Abstract

The main contributions to FOC image imperfections are discussed. A set of new RSDP pipeline algorithms and calibration files for FOC is described based on this understanding of the FOC.

This is a proposal for discussion.
The new algorithms will be coded in IRAF SPP and would run both in IRAF and the RSDP pipeline. A future report will address non-pipeline processing.

DISTRIBUTION:

FOC Project: H. Kröger, R. Laurance, M. Miebach, B. G. Taylor, R. Thomas, N. Towers
IDT: entire FOC IDT
1SB: J. C. Blades, C. Cox, J. Crocker, B. Gillespie, P. Greenfield, H. Jenkner, D. Macchetto,
A. Nota, P. Parese, M. Rafal, All Instrument Scientists
OPD: S. Parsons, D. Giaretta, W. Pence, R. Hanisch, P. Van West
OSB: J. Rose
ST/ECF: R. Albrecht, P. Benvenuti, R. Fosbury
The science image’s instrumental parameters

- The selection of calibration frames is limited to the current scheme of selection based on
- The process cannot be interactive

We must bear in mind the restrictions that operate within the SOGS pipeline implies:

establishments and provides a natural place for such looks.

for the GO to reprocess the data. The IRAF system will be widespread throughout astronomical
archive data with current images. The only practical alternative will be to provide the tools
previously images will not be reprocessed each time, and yet GOs may wish to compare
with so many other instruments in the past, with the IUE satellite as a very good example.

Moreover, in the future, we will undoubtedly refine the calibration process, as has happened

It is important that the algorithms be available in IRAF as it seems clear that these will be
also be available in IRAF.

It is time to explicitly describe a new FOC pipeline which could operate within SOGS, and

- There should be time well before launch to implement the new pipeline
- We understand more about how the corrections should be done
- It now seems possible to replace the PHA code for the correction algorithms by IRAF
- It may now be possible to work around. However, because

The current RSDP pipeline for FOC images has many well known deficiencies, some of which

Introduction
- there are limits on the amount of CPU time and power available, although the main constraint on RSDP sizing is WFPC processing and in any reasonable scheme the FOC CPU time will be a small perturbation.

- there are constraints on the total size of the calibration files we can reasonable use.

Fortunately since we are not now attempting to perform an ITF correction the last two constraints become easier to cope with since the TRW pipeline was sized to cope with the ITF files which could have been very large and the processing very CPU intensive. Moreover the use of compressed IRAF image masks makes handling of data quality masks more practical.

It is true however that interactive processing by a GO may yield superior results. Processing objective prism or cross-disperser data will certainly required user interaction. We should be in the position to supply a supplementary set of tools to perform this sort of interactive correction which would co-exist with the pipeline tool in IRAF.

The type of files produced by the pipeline will be the same as now, except that there will be separate bad pixel masks for each data image rather than a single data quality mask.

- raw image - and associated bad pixel mask
- photometrically corrected image - and associated bad pixel mask
- geometrically corrected image - and associated bad pixel mask
- transmission profile assumed for optical chain, including DE?????
- information on the geometric transformations performed — for example the optical and detector distortion fields used to correct the image. These would be useful in any subsequent reprocessing of the data.

There will be associated changes in the contents of the calibration files, in part to make these more compatible with those used in IRAF and in part to include more information in the file header to allow the corrected image headers to be set accurately.

The main contributions to FOC image imperfections such as distortion and noise are described next. This discussion is important because only when we understand where these effects arise can we remove them in the correct, inverse, order. Following this we detail the calibration steps and finally the correction algorithms are discussed in detail.
4. Image formation

(a) change in sensitivity across format scanned

(b) distortion

6. Camera — all these may be format dependent:

(a) lost in the noise.
(b) attenuation in the sense that individual photons may be diminished and
(c) distortion?

6. Compensating options:

(a) dark noise
(b) distortion

4. Intensifier effects:

(c) Reseau marks introduced into the image

(b) "absolute DE" — the overall scaling factor

(a) "relative DE" — the spatial variations introduced

3. Incident on photodetector, effects classified as:

(a) distortion by mirrors, HRAs, or spectrograph

(b) attenuation by filters, mirrors, HRAs, or spectrograph dispersing

(a) vignetting by FOC

2. Travels through FOC options:

(a) vignetting, distortion and attenuation in the ST options

1. High/through ST options:

Points should be covered.

The processes are simplified, partly because some are not well understood, but the essential
various instrumental signature components. Detailed physical descriptions are omitted and
We describe next the image formation process in the FOC with emphasis on the origin of

2 FOC Image Formation
(c) change in sensitivity with ZOOM mode on
(d) pattern noise, e.g. fringing between G4 grid and target
(e) hot spots
(f) fly-back line on the image

7. electronics — all these may be format dependent:
   (a) saturation effects in VPU
   (b) pattern noise?
   (c) random noise?

3  FOC image correction

As a general principle the imperfections should be removed from the raw image in the inverse order to that in which they arose. Now the main problems are that:

1. we may not know how to apply the inverse operator, but this really only applies to the non-linear effects. The rest are simple scaling or flat fielding or distortion.

2. we may not be able to separate similar effects, such as geometric distortion arising in the intensifier and the camera. In principle we may be able to use hot spots to do this.

3. even where we can separate the distortions of the optics and the detector we do not wish to apply two separate geometric corrections as each time we apply the correction we smear the image.

We propose to do the following:

1. we ignore ITF nonlinear effects, except that we may flag pixels suspected of being saturated beyond a specified limit

2. we apply all the scaling factors at one time, for example absolute DE, filter transmissions etc.

3. we geometrically correct the image only once
tion of the raw image and divide these two instead. We thus avoid pearing the
however instead we can distort the Relative DE image to match the dis- 
(q) now we should geometrically correct the image and divide out the Relative DE,
(a) subtract scaled dark noise — if we have any fixed dark noise which seems
unlikely

3. Interferer
from detector distortion
(a) ignore the separate component of geometric distortion as we cannot separate it
(b) compensate optics
spatial frequency pattern
account any sensitivity dependence on image format if we look on it as very low
(c) divide out fixed pattern noise — this effectively includes a factor to take into
the shot noise
this may have severe effects on, for example the Hy-back line
from detector distortion
(b) ignore the separate component of geometric distortion as we cannot separate it
(a) ignore saturation effects (except for low

only these parts are format dependent
1. Electronics and camera

4.1 Normal Imaging

We arrive at the following correction scheme based upon the origin of the effects:

4. FOC correction scheme

5. We assume that pattern noise is multiplicative, since otherwise it would lead to disp-
har-feeding operations may be combined.
4. We must apply the spatially dependent variations in the correct order although adjacent
science image. Note: this would result in the largest increment to CPU usage but a nearest neighbour approximation may be adequate for the Relative DE image distortion since this should vary only slowly with position.

4. ST/FOC optics

(a) include vignetting in the Relative DE correction image
(b) geometrically correct the data image with a combination of detector and optical distortions
(c) apply an overall scaling factor to include all the attenuation effects and the factor to convert from counts to energy units
(d) flag the expected reseau mark positions
<table>
<thead>
<tr>
<th>Combine, into overall scaling factor</th>
<th>Attenuation</th>
</tr>
</thead>
<tbody>
<tr>
<td>not measurable — Ignore</td>
<td>Distortion</td>
</tr>
</tbody>
</table>

**Combining Options**

<table>
<thead>
<tr>
<th>Age, after scaling for exposure time</th>
<th>Dark counts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correctly registered with the science image</td>
<td>Geometrically corrected the relative DE image, and also combine this distortion into Geometrically corrected image</td>
</tr>
</tbody>
</table>

**Inusher**

<table>
<thead>
<tr>
<th>Rescan marks</th>
<th>Relative DE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Focal plane with the science image</td>
<td>Absolute DE</td>
</tr>
<tr>
<td>Halved with image geometrically rectified</td>
<td></td>
</tr>
</tbody>
</table>

**Detector Photocathode**

<table>
<thead>
<tr>
<th>Det. combine into overall scaling factor</th>
<th>Attenuation</th>
</tr>
</thead>
<tbody>
<tr>
<td>combine with detector distortion</td>
<td>Distortion</td>
</tr>
</tbody>
</table>

**FOC Options**

<table>
<thead>
<tr>
<th>Focal length</th>
<th>Attenuation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apply combined overall scaling factor in</td>
<td>Distortion</td>
</tr>
<tr>
<td>tones with combined optics and detector distortion</td>
<td></td>
</tr>
<tr>
<td>Geometrically corrected the science image</td>
<td></td>
</tr>
</tbody>
</table>

**ST Options**

<table>
<thead>
<tr>
<th>Image of table to the top</th>
<th>Attenuation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Applied to the image in order from the bottom</td>
<td>Distortion</td>
</tr>
</tbody>
</table>

**Summary of FOC Image Formation and Correction**

<table>
<thead>
<tr>
<th>Direct</th>
<th>Summary table</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4.2 Summary table</td>
</tr>
</tbody>
</table>
### Summary of FOC image formation and correction (cont.)

<table>
<thead>
<tr>
<th>Effect</th>
<th>Correction</th>
</tr>
</thead>
<tbody>
<tr>
<td>affect the image in order from top to bottom of the table</td>
<td>applied to the image in order from the bottom of the table to the top</td>
</tr>
</tbody>
</table>

**Camera**

<table>
<thead>
<tr>
<th>Effect</th>
<th>Correction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distortion</td>
<td>not measurable separate from the intensifier distortion — unless we can use the pattern noise — initially ignore this, although this may have an effect on correction on the pattern noise and fly-back line</td>
</tr>
<tr>
<td>Change in sensitivity across format</td>
<td>flat field this out</td>
</tr>
<tr>
<td>Pattern noise e.g. fringing between G4 grid and the target</td>
<td>flat field this out</td>
</tr>
<tr>
<td>Change in sensitivity in ZOOM mode</td>
<td>incorporate in pattern noise</td>
</tr>
<tr>
<td>Hot spots</td>
<td>flag these in the BPL</td>
</tr>
</tbody>
</table>

**Electronics**

<table>
<thead>
<tr>
<th>Effect</th>
<th>Correction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saturation effects in the VPU</td>
<td>ignore</td>
</tr>
<tr>
<td>Pattern noise?</td>
<td>cannot separate this from the camera pattern noise</td>
</tr>
<tr>
<td>Random noise</td>
<td>ignore</td>
</tr>
</tbody>
</table>
10
After the "local" pattern noise and the position of the back
(b) distortion in the camera section which is being ignored but which, if present, will
exceed specified limits.
(a) ITF saturation - this can be minimized by ensuring that the count rates do not

3. Integrated effects:
2. Noise in the calibration files
1. Random noise in the science image

them known to GO.

effects and also to ensure that we understand and can minimize the known ones and make
tant to enumerate them and estimate their magnitudes in order to detect any unexpected
There will be residual errors in the corrected images arising from various factors. It is impor-

4.5 Residual errors

use of the data.
A task could be performed entirely within the pipeline, but must of course be vetted before
then would be a higher for generation of a new geometric calibration file. Indeed this
expected would be summarized for the operations. Subsequently large differences ( more than 0.2
geometric reference file. A summary of these locations and the differences from those ex-
image and compare these to the expected position based on information in the corresponding
image made with the internal LID's not used by the pipeline would automatically locate resonant marks in the
Images made with the internal LID's, not used by the pipeline, would automatically locate resonant marks in the

4.4 LID Images

Geometrically corrected science images as is presently done.

Image: However in practice one may be able to avoid this and instead divide this into the
image and then that in principle be distorted to register with the raw science
Basically similar to normal imaging except that the Relative and absolute D are combined

4.3 Spectrographic mode
(c) components of the patterning which are not fixed, for example temperature dependent effects.

(d) smearing in geometric correction will be expected to leave traces of scratches on the photocathode

(e) the use of a single Relative DE file for a wide band observation may mean that we have uncorrected photocathode signature. This will be minimized if the Relative DE chosen corresponds in wavelength to the most signal from the source — but this may change across the image and no single Rel. will suffice.

5 Detailed discussion

Next we describe the various calibration steps in detail. The algorithms are straightforward for the most part. The geometric correction algorithm is similar to that used currently. Of equal importance are the selection criteria, the header information and the treatment of associated bad pixel lists. The inclusion of the BPL will effectively double the number of files being dealt with. In principle this may cause problems with restrictions on the number of files which may be open at one time, but in practice each BPL is opened, read into memory and closed so there should be no problem in this regard.

We start with the general problem of flagging pixels and then proceed to the particular corrections.

5.1 Bad Pixel List (BPL) management

Pixel flagging would correspond basically to setting bits in the associated BPL. A convention is needed, for example bit 1 set may indicate that the pixel may be affected by reseau, bit 2 set may indicate that there may be saturation effects. This needs to be worked out in detail, possibly in coordination with the WFPC. It is not clear whether one can define an order for the severity of each flag but some rough order or grouping would simplify an IRAF user’s specification of appropriate flags to be used or ignored. Combining flags would consist of “or”ing the flag values together.

Pixels would be flagged based on information from the following sources:
OR with other BPL information:
  
  
  None
  
  Header information
  
  An IRAP BPL

Format of calibration file

SAMPLEN and LINEEPF1 (an PIJOFRMT)
The basic BPL would be selected by OPTICALY. Image size (SAMPLEP, LINEEPF1, selection criteria for calibration file

High error in position:
and has a circle 4 pixels in radius to take into account the size of the reseau as well as any
disturbance is expected to be less than that for hot spots, or we may specify reseau positions
of a circle around each point of some chosen radius, for example a radius of 2 pixels. If
since the calibration file may not register exactly with the science image it seems sensible

4. Based on BPL associated with the calibration images.

  To the pixel in the corrected science image.

would involve "corrections" of the bil values of all pixels which would contribute
a similar distortion on the BPL. Note that the geometric correction of the BPL
positions in the geometrically corrected image would be tracked when we perform
their

3. Based on GDO calibration file

In a 256 by 256 image.

Separate BPL may be of use; however, for example, for the glitches at say the 256
positions of glitches and known hot spots — most or all of these would

2. Based on an input BPL

(c) Possible saturation affected areas ???

(b) Hot spots (count rate exceeding a specified amount per frame)

(a) Lenticular droplets

1. Based on the input image
5.2 Format dependent variation and Pattern noise

These two effects are combined — as indeed they are physically. However we should be careful when creating the format dependent part to remove effects due to changing pixel size, otherwise this would defeat the use of the Jacobian in the geometric correction. It is preferable to keep the geometric correction Jacobian since that includes any size effects from the optical distortion.

- selection criteria for calibration file
  based on detector and camera format

- format of calibration file same size as science image

- header information TBD

- algorithm
  we must ensure we remove the pixel size factor from the calibration file when generated.

- bad pixel mask
  may not be required

5.3 Dark count

The detector dark count

- selection criteria for calibration file
  as before

- format of calibration file
  image as before

5.4 Relative DE

- selection criteria for calibration file
  as before
The BPl must be appropriately geometrically corrected, as well as the image.

- bad pixel mask
- additional header info about the required size of the output image
- header information
- a reason the table is used in IRAP
- format of calibration file
- selection criteria for calibration file

The reason marks can be flagged.
4. The file should contain the coordinates expected for the reason in the raw image so that images taken that imprint to avoid chopping corners.
3. The correction algorithm will need to be extended to allow the generation of larger images than the input, to avoid chopping corners.
2. The main change lies in the reference file given to the algorithm. We would like to en-
1. Currently the basic algorithm is more or less sound

5.5 Geometric correction

An additional BPl may be associated with this image.

- bad pixel mask
- as before
- header information
- full format image
- format of calibration file
5.6 Absolute DE correction

1. - compute some factor which a user may use to convert image counts to either photon or energy units
   - since the actual factor is source dependent we wish to supply the number in the header, for a user to use or ignore as thinks fit.
   - a small file containing the curve of wavelength dependence of throughput assumed should be delivered with the output products.

   - selection criteria for calibration file
     as before

5.7 Spectrograph DE correction

1. must NOT process spectrograph images with cross-disperser

   - selection criteria for calibration file
     as before
   
   - format of calibration file
     as before
   
   - header information
     add information about dispersion and order corrected for
   
   - algorithm
     as before
   
   - bad pixel mask

5.8 Automatic reseau location in LED images

1. some non-interactive method of locating reseau marks, allowing the possibility of large changes. - engineering parameter dependence of reseau positions may be usable

2. a comparison with the current expected reseau positions may be given, perhaps giving a warning if the differences are too great.
References

TBD

6.2 Object classification/identification

Investigation of background variation with orbital position. The mean of the bottom, say, 10% of the image histogram may be stored to be used in

6.1 Extraction of statistical data

6. Preprocessing

- May not be possible in RSDP
- Possible positions and relative magnitude of ghosts should be marked

6.9 Ghosts