NHS Breast Screening Programme

NHS Cancer Screening Programmes

Calculation Of Quantitative Image Quality Parameters

Notes Describing the Use of OBJ_IQ_reduced

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PREFACE

The program OBJ_IQ_reduced was developed to enable the calculation of quantitative image quality parameters for x-ray detectors. These parameters include the presampling modulation transfer function, detector non-uniformity, the variance image (used to assess noise uniformity) and the noise power spectrum. The program is intended for use by physicists who wish to establish more quantitative measures of x-ray detector imaging performance. The latest version is freely available from the Clinical Physics Clinical Academic Unit at Barts and The London NHS Trust. Contact the author, Nick Marshall, at nick.marshall@bartsandthelondon.nhs.uk.

1. SCOPE

File: OBJ_IQ_reduced_v2.sav

This program can be used to calculate the following quantitative image quality (IQ) parameters:

- detector non-uniformity
- variance image (VI)
- signal to noise ratio image (SNRI)
- modulation transfer function (MTF) from an edge image
- noise power spectrum (NPS).

These measurements relate to the x-ray detector: the resolution (presampling MTF of the x-ray converter layer), non-uniformity of signal and x-ray noise across the detector and the noise power spectrum (calculated from regions of interest sampled across the detector). While all of these parameters affect the image quality of an x-ray imaging system as a whole, they will not currently tell us if a system meets some specified global image quality criterion. In the case of digital mammography systems, the system image quality will depend on additional factors such as beam quality selection (contrast), the target air kerma used to form the image (mean glandular dose) and the influence of scattered radiation. However, objective image quality parameters should help to ascertain if the detector is functioning normally, ie a health check for detectors.

This is simple objective IQ calculation software. File handling is very basic – there is no attempt to provide a DICOM file list for patients, studies, series, etc. Files are simply selected and loaded. For exmple, this software is not intended for batch processing of a large number of noise power spectra. Users who want this will have to write their own software.

Output is simple: .csv text files and some images. Please provide feedback on the information saved so this can be amended to suit the user's requirements.

Before proceeding, users should have at least a basic notion of the theory that underpins these measures. For example, see Chapters 2, 3 and 4 in *Physics and Psychophysics* Vol. 1 (eds. Beutel J, Kundel HL and van Metter RLV) (SPIE, Bellingham, WA, USA). See Appendix 1 for a list of useful papers.

2. INSTALLATION

Step 1

You will need to download IDL Virtual Machine to run OBJ_IQ_reduced_v2. To do this, go to the ITT download page at http://www.ittvis.com/download/download.asp, click on the appropriate version for your platform and follow the instructions for downloading and running the installation file on your PC (you will need to register first). Downloading will take some time (eg version 7.0 for Windows is 269 MB). When installing, select the option to run without a licence – this will give you the ability to run the VM (which is free) but not the full IDL software.

Step 2

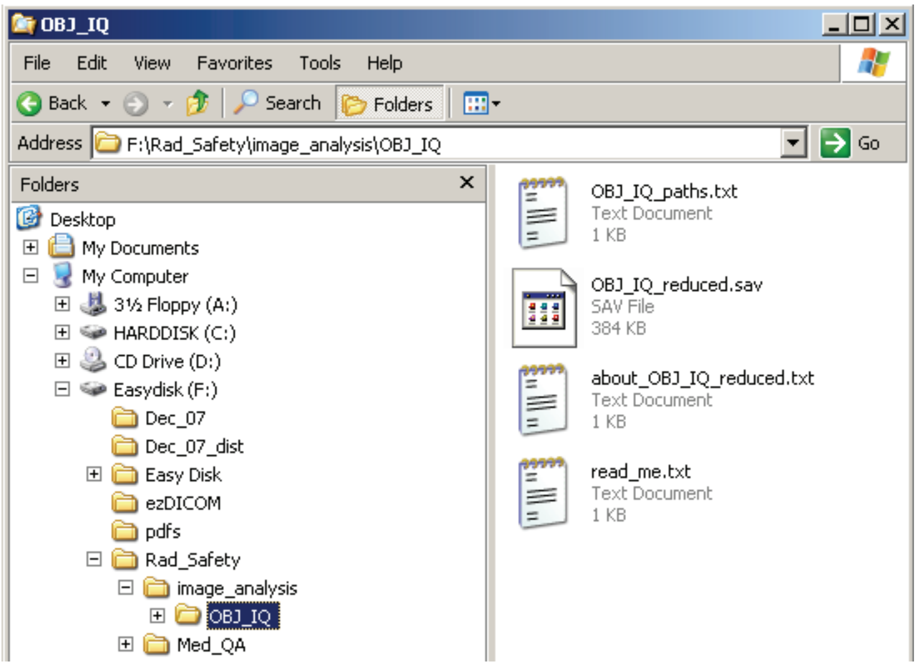
Create a directory for the Objective IQ program and the paths file, eg

'C:\users \image_analysis\OBJ_IQ\'

Copy the files:

'OBJ_IQ_reduced_v2.sav' (main IQ program)
'OBJ_IQ_paths.txt' (file containing path information)
'about_OBJ_IQ_reduced_v2.txt' ('about' file)
'read_me.txt'

into this directory.



The file 'OBJ_IQ_paths.txt' holds the *ip_dir* (where the program looks for images) and the *op_dir* (destination for the results).

An example ‘OBJ_IQ_paths.txt’ is:

```
ip_dir
C:\
op_dir
Q:\Rad_Safety\Med_QA\SBH\AMX700_1\Dec_07\
```

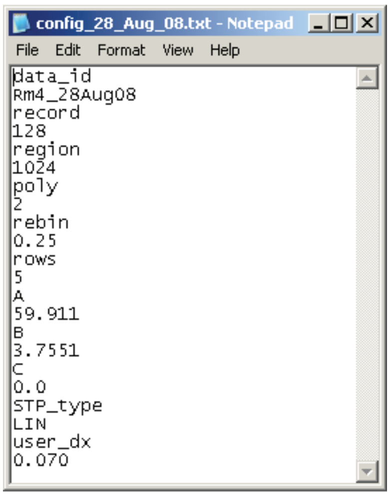
Note: There must be an output directory – if this is not specified then the program will hang up.

Step 3

Create a directory for the program output (eg the quality assurance (QA) visit or experiment for the particular detector of interest) and copy the configuration file (‘OBJ_IQ_config.txt’) into this directory, eg:

‘Q:\Rad_Safety\Med_QA\SBH\AMX700_1\Dec_07\’

Change the config.txt file name to reflect the results, eg ‘config_AMX700_Dec07.txt’. The config.txt file should then be edited so that it contains information relevant to this particular measurement. The idea is that the relevant config.txt files are kept with the output for a particular QA visit, and this allows the user to see the settings that were used when processing the images. It also allows quick setup of the STP coefficients and default settings for NPS etc. when processing or reprocessing results.




```
data_id
Rm4_28Aug08
record
128
region
1024
poly
2
rebin
0.25
rows
5
A
59.911
B
3.7551
C
0.0
STP_type
LIN
user_dx
0.070
```

Example config.txt file

The config.txt file holds the following setup data:

- data_id: used to identify the results – this ID is included in the filenames of the output files
- record: size of the square NPS ROI in pixels
- region: size of the square region of image in pixels from which the NPS ROIs are extracted
- poly: order of the polynomial used for removing low frequency effects in the image (‘detrending polynomial’)
- rebin: the size of the spatial frequency bins used when rebinning the NPS and MTF results
- rows: the number of rows out from the u and v axes used when sectioning the NPS
- A: the A coefficient of the STP
- B: the B coefficient of the STP
- C: the C coefficient of the STP

- STP_type: type of STP – this must be LIN, LOG or SQRT
- user_dx: this is the pixel size of the system for systems where there is no pixel size in the DICOM header and is ignored if the pixel size is found in the header.

The config.txt file must have exactly 22 lines and the data must appear in the order shown above otherwise the program will not be able to read the data or will read data into the wrong field. Note that all the values that are set using the config.txt file can also be set/changed manually by the user.

Step 4

Run ‘OBJ_IQ_reduced_v2.sav’.

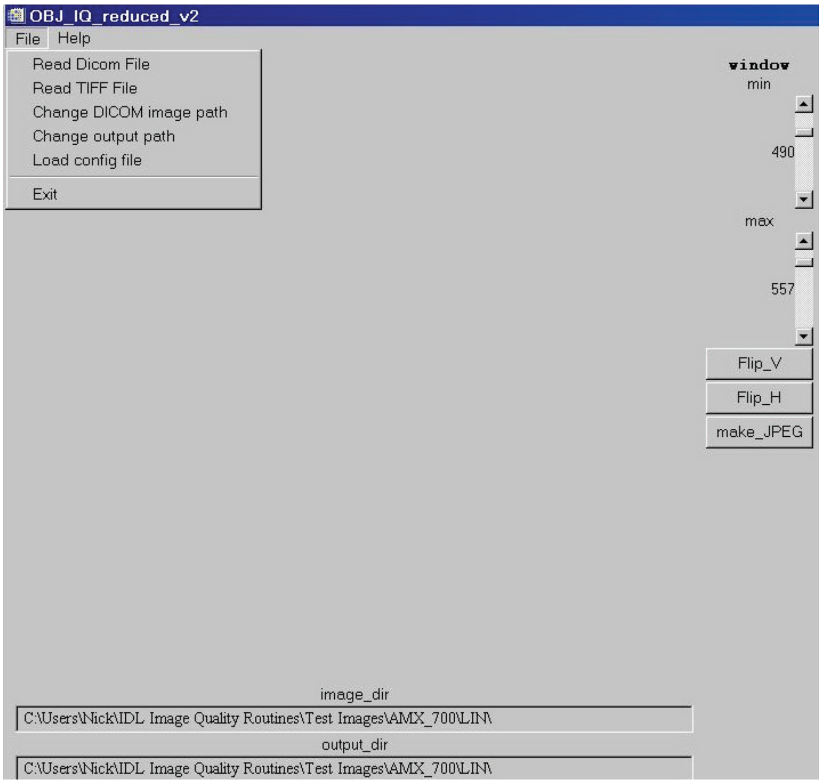
3. USING 'OBJ_IQ_REDUCED_V2'

Important: note on program flow. The software expects all the desired parameters and settings (eg 'VERT MTF' button) to be selected/set before activating a function, eg pressing the 'MTF' button to calculate the MTF. Once the 'MTF' function is activated, parameters such as 'VERT MTF' and sub_pixel_size cannot be changed. (If you activate a function and then want to change something, just go ahead and perform the calculation anyway and then set the correct settings and recalculate – a cancel or abort button may be added in the future.)

In general, load the image you want to analyse and then activate the function. The exception is NPS, in which case you press NPS and the program will ask for the images to be analysed.

3.1 File handling

The very basic file handling options are shown below:



3.1.1 Changing directories

Click on File>'Change DICOM image path' and select the location of the image files. Click on File>'Change output path' and select the directory for the results. The program should remember the last directories used.

3.1.2 Load config.txt

Click on File>'Load config file' and select the relevant config file. This should be kept in the output directory with the other results. (The config file should be amended so that it contains the relevant information for the particular measurements of interest.)

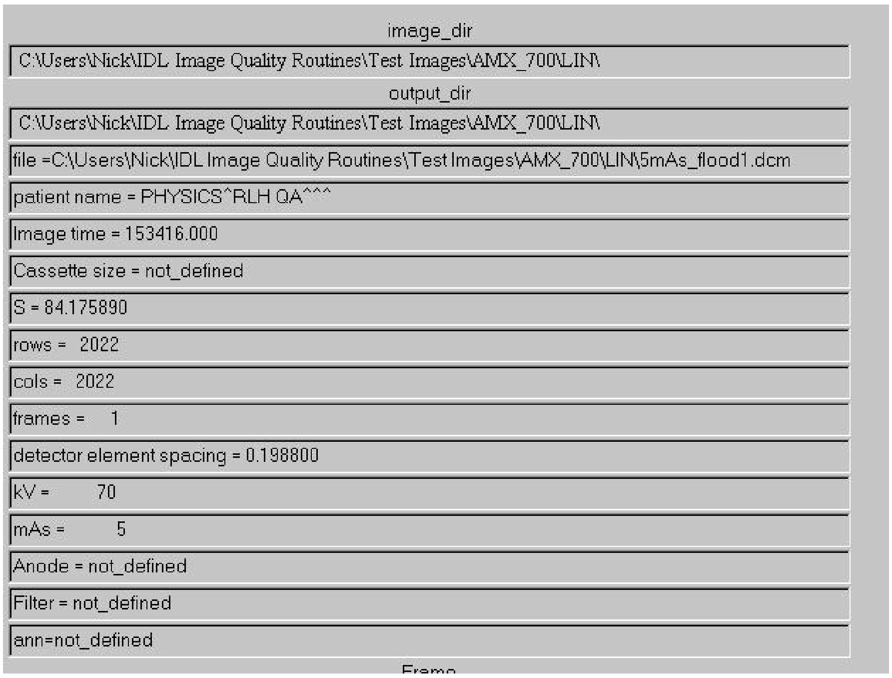
3.1.3 Load DICOM image file

Click on File>'Read DICOM file' and load the relevant image file. Images can be flipped vertically and horizontally using Flip_V and Flip_H (make_JPEG is a very basic routine to save the image as a .jpg file; headroom for the conversion is controlled by var scale_factor in the variance image section).

3.1.4 Read DICOM header

The program will perform a limited read of the DICOM header; the default position is to attempt to read the header. If this fails (DICOM files are notorious for header abuse) then untick this option and try again (bottom of the NPS column).

The following header information is shown, if present:



Detector pixel spacing is essential for the NPS and MTF calculations. The program extracts this information from the header tag (0018,1164); if absent from the header (fluoroscopy systems etc.), the program uses the value assigned in 'user_dx' in the config.txt file. (This has just been introduced – please report instances when this fails.)

Note that junk data may appear in the DICOM fields, depending on whether the read was successful. If detailed DICOM header information is required, then a dedicated DICOM image reader should be used (eg Offis or DICOMworks). The bottom field ('ann') tries to read any user annotations that have been applied to the image; this should help in the identification of images. If 'read header?' keeps failing for certain DICOM images, then please let me know (also send a copy of the DICOM file so I can examine the problem).

The reduced version will not read sequences of images; 'OBJ_IQ' is needed for this.

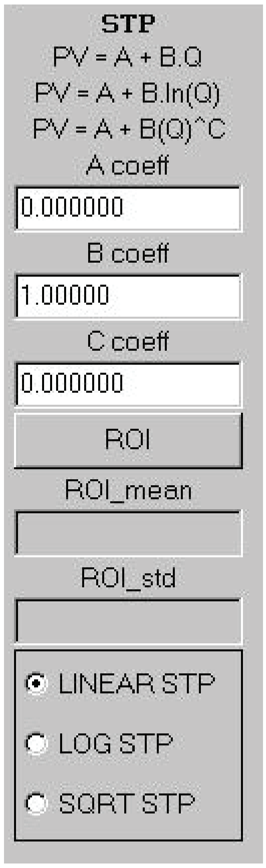
3.1.5 Load TIFF image file

Click on File>'Read TIFF file' and load the relevant image file.

3.2 Signal transfer property (STP)

The STP is used to linearise the image. There are two primary options for this.

3.2.1 IEC 62220-1 conversion function method



1. Plot pixel value (PV) taken from the appropriate image (fixed gain and no spatial frequency image processing such as unsharp masking etc.) against number of photons (Q) at the detector input plane. The correct number of photons/mm^2/μGy must be used for the beam quality used to acquire the STP flood (NPS) images.
2. Fit the relevant function – three functions are supported – and note the parameters of the fit:

   Linear

   $\mathrm{PV} = A + BQ$

   Logarithmic

   $\mathrm{PV} = A + B\ln(Q)$

   Square root

   $\mathrm{PV} = A + B(Q)^C$

   where $C \sim 0.5$.

3. Enter the parameters into the boxes provided.
4. Check the function button (the program defaults to 'LINEAR STP').

If using this type of normalization for NPS calculation then the button:

must be checked.

During the calculation of NPS and MTF, the image is first converted to a distribution of x-ray photons using the inverse of the STP. This linearises the image and removes the gain. The IEC method gives NPS_Q with units of mm^{-2}, a quantity that increases as the air kerma to the detector (ie Q) increases. To obtain the normalised NPS (NNPS), NPS_Q must be divided by Q^2, where Q is the number of photons (per mm^2) used to acquire the image from which the NPS was calculated. NPS increases as exposure increases (the variance increases with increasing exposure, as expected).

3.2.2 Air kerma STP conversion method

1. Plot pixel value (PV) against air kerma at the detector entrance plane (K_a).
2. Fit the relevant function – three functions are available – and note the parameters of the fit:

    Linear

    $$PV = A + BK_a$$

    Logarithmic

    $$PV = A + B\ln(K_a)$$

    Square root

    $$PV = A + B(K_a)^C$$

    where $C \sim 0.5$.

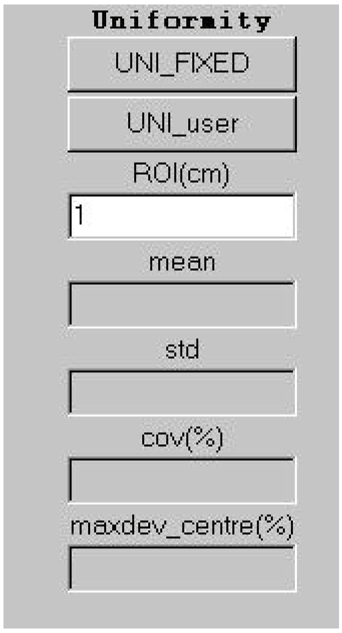
3. Enter the parameters into the boxes provided.
4. Check the function button (the program defaults to ‘LINEAR STP’). The STP function type can also be specified in the config.txt file.

During the calculation of NPS and MTF, the image is linearised (ie solved for K_a in the above equations). Once this has been done, the mean of the image should be equal to the air kerma used to acquire the image (a useful check on the STP result). This method gives the NNPS directly (units of mm^2); the last step of the NNPS algorithm is to calculate the average value of the NPS region (ie K_a) and then divide the NPS ensemble by this value (K_a^2) to normalise for the signal. Note that NNPS decreases as the air kerma to the detector increases. Also, if using this method to obtain the NNPS directly, the NNPS will be correct only if the dosimetry is correct.

3.3 Region of interest (ROI)

This places a 1 cm × 1 cm ROI at the image centre. <right-click> and the program calculates the mean and standard deviation and displays these in the boxes ROI_mean and ROI_std. (The ROI button is located in the STP section.)

3.4 Detector non-uniformity



The user selects ROI size in cm for the non-uniformity calculation – the default is 1 cm. Detector non-uniformity can then be calculated using two methods: UNI_FIXED and UNI_user. For both of these routines, the image is linearised via the STP and therefore the correct STP information must be set before calculating non-uniformity.

UNI_FIXED trims the image by 1 cm around the edge and then calculates the number of ROIs that will fit in this area. The image is then linearised using the STP and the mean PV is calculated for each ROI within the image. The routine returns the mean, standard deviation and coefficient of variation (cov) of these ROIs together with the maximum deviation from the centre ROI. These values are also saved in a file:

```
'UNI_fix_' + data_id + '.csv'
```

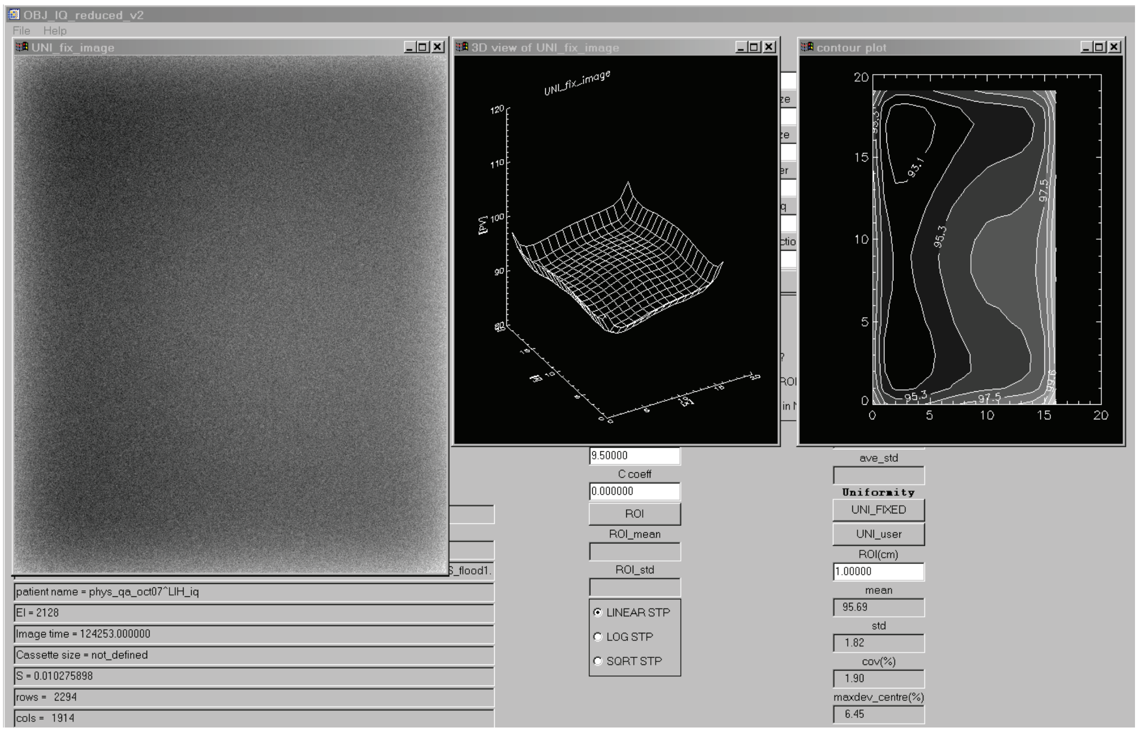
along with the mean PV for each ROI as a function of column and row (cm).

UNI_user allows the user to select the region for the non-uniformity calculation using an ROI – the initial ROI size is 1 cm in from the edge of the image. Resize and move the ROI as desired. When happy with the size and position, <right-click> to run the non-uniformity calculation. The program calculates the number of ROIs that will fit into the selected region. The image is then linearised using the STP, and the mean PV is calculated for each ROI within the image. The routine returns the mean, standard deviation and coefficient of variation (cov) of these ROIs together with the maximum deviation from the centre ROI and maximum deviation from the mean of the ROIs. These values are also saved in a file:

```
'UNI_user_' + data_id + '.csv'
```

along with the mean PV for each ROI as a function of column and row (cm).

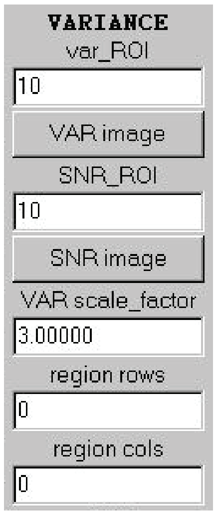
Three-dimensional wireframe and contour plots are shown of the detector non-uniformity:



3.5 Variance image (VI)

Before calculating NPS and MTF, it is recommended that a variance image of one of the NPS flood images is examined. This should reveal any severe artefacts that may be present; the noise (PV variance) should be uniform across the image.

The image is linearised via the STP before calculation of the VI. For a linear system, the VI could be calculated without STP inversion; however, for consistency it is recommended that the exact STP is used. STP correction is required for LOG or SQRT systems as the air kerma used at image acquisition will set the position of the image along the STP and therefore govern the degree of stretch or compression applied by the STP to the images. There is a chance (albeit quite small) that this could enhance or hide any artefact that may be present, and therefore STP inversion is recommended. If absolute values of variance per variance ROI (in terms of either air kerma or photon number) are required, then the exact STP must be used (using either PV versus air kerma or PV versus number of photons, as required).



Use VAR_ROI to set the sample ROI size used in the VI calculation (10 × 10 pixel ROI is set as default). The default VI region is the full image size minus 20 pixels, ie full image minus a 10 pixel gap around the edge. To move the VI region, <left-click> on the VI region, hold and move to the required position. To resize the VI region, hold down <CTRL> and <left-click> on the edge or corner that you want to adjust and move the mouse to resize as required. The user can also enter region size in pixels. Once happy with the size and position, <right-click> to calculate the variance image.

Variance is calculated using the IDL code:

```
stats = moment(VAR_array)

variance = float(stats(1))
```

The greyscale used for the VI is: low variance = black, high variance = white. Variance can be extremely high for some sample ROIs (dead pixels, hot pixels, etc.) and therefore has to be compressed to fit into an 8-bit .jpeg image. The variance image is normalised using the factor 'VAR scale_factor' – the default value for this scaling factor is 3, ie 3 × mean variance is allowed as headroom:

```
maxval = max(VAR_image, min=minval)
stats = moment(VAR_image)
test = VAR_scale_factor*stats[0]
maxval = test
VAR_image *= 255.0/maxval
```

3.5.1 VI output

All the routines in 'OBJ_IQ_reduced_v2' (NPS, MTF, etc.) use the box 'data_id' to label the results.

The program saves both the region for which the VI is calculated:

```
'VAR_region_' + data_id +'.jpg
```

and the variance image itself:

```
'VARim_'+ data_id +'.jpg'
```

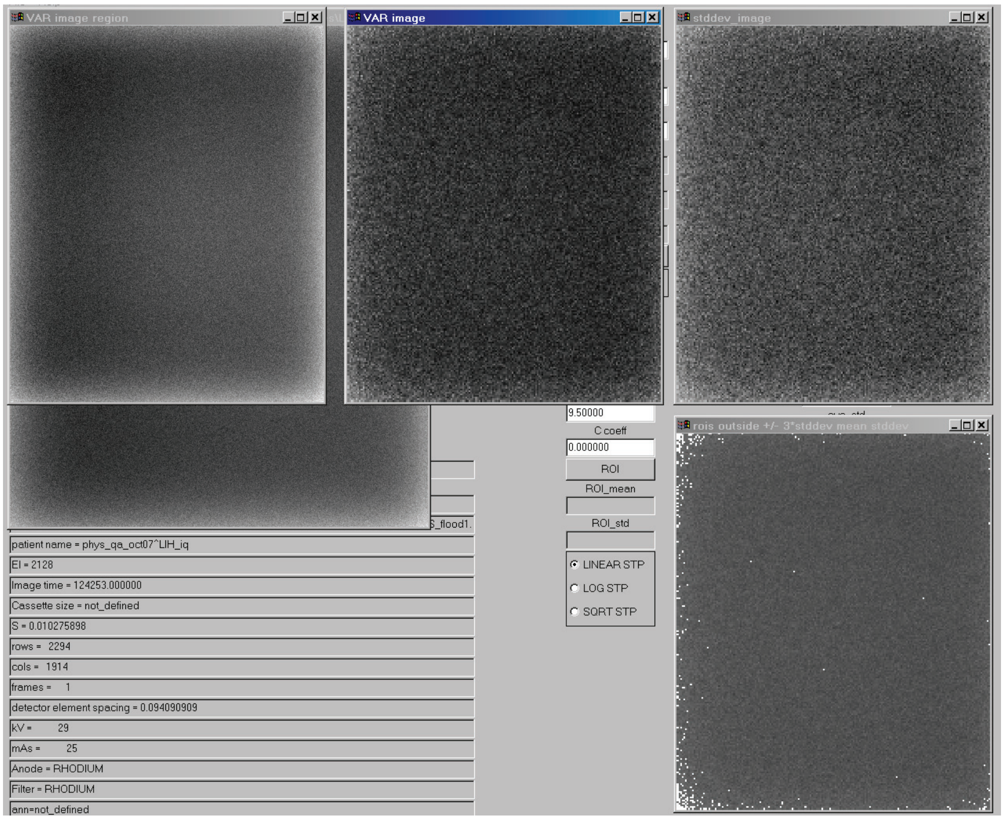
a standard deviation image:

```
'stddevim_'+c_id+'.jpg'
```

an 'artefact' image:

```
'ARTim_'+c_id+'.jpg'
```

The program also identifies pixels (ie pixel blocks) in the standard deviation image that are outside mean standard deviation ± 3 × stddev of mean standard deviation. These are marked as white pixel blocks on the standard deviation image. This is an attempt to identify scratches etc. in CR non-uniformity images. No numerical output currently.



3.6 Signal to noise ratio image (SNRI)

SNRI is similar to the VI, but this time the SNR is calculated for some nominal ROI and assigned a greyscale value. As with the VI, the image is linearised via the STP before calculating the SNR image. Use SNR_ROI to set the sample ROI size (10 × 10 pixel ROI is set as default). The default region is the full image size minus 20 pixels, ie full image minus a 10 pixel gap around the edge. To move the SNRI region, <left-click> on the region, hold and move to the required position. To resize the SNRI region, hold down <CTRL> and click on the edge or corner that you want to adjust – move the mouse to resize the region. Resize as required. The user can also enter region size in pixels. <right-click> to calculate.

Calculated as follows (if standard deviation for a given SNR image pixel is zero then the SNRI is set to 0 (black)):

```
stats = moment(SNR_array)
variance = stats(1)
mn = stats(0)
sd = sqrt(variance)
if (sd eq 0) then SNR = 0 else SNR = float(mn) / float(sd)
```

Low SNR = black; high SNR = white. SNR can be high/low for some sample ROIs (although extremes are not as high as those seen for the VI) and therefore the SNRI is compressed to fit into a .jpeg image. The SNRI is also normalised using the factor ‘VAR scale_factor’ – the default value for this scaling factor is 3, ie 3 × mean of the SNRI is allowed as headroom:

```
maxval = max(SNR_image, min=minval)
stats = moment(SNR_image)
test = VAR_scale_factor *stats[0]
maxval = test
SNR_image *= 255.0/maxval
```

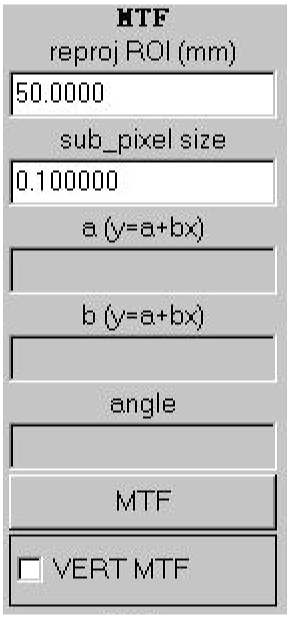
3.6.1 SNRI output

The program saves the SNR image:

```
'SNRim_' + data_id + '.jpg'
```

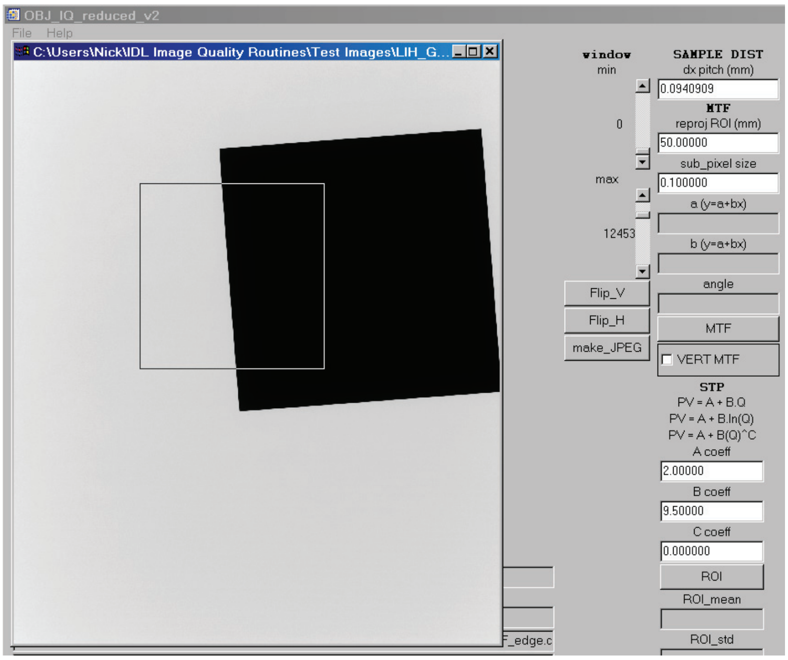
3.7 Modulation transfer function (MTF)

3.7.1 Calculation steps for the MTF

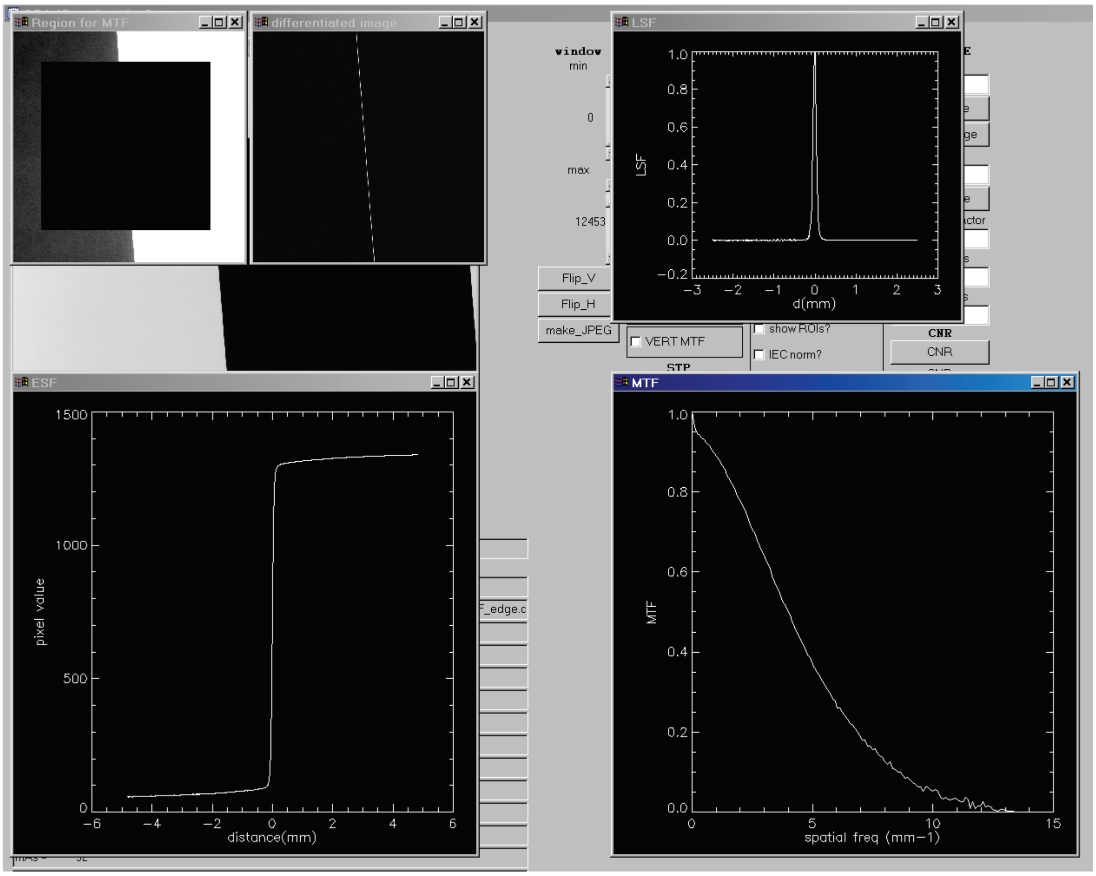


1. Load the image containing the MTF edge.
2. Check that the 'dx pitch (mm)' box has the correct value for the system being studied. The value taken from the DICOM can be overwritten by the user if this value is incorrect.
3. Enter an appropriate label for 'data_id' (eg Rm2_Dec06).
4. **reproj ROI (mm)**: Enter the re-projection region size (default is 50 mm × 50 mm). The area of image/edge will affect the MTF result to some degree – using a small region of image can underestimate any low frequency trends that may be present in the MTF. However, using a large region of image can lead to inaccuracies in fitting the equation to the edge and hence in the estimation of the edge angle. This in turn can lead to strange edge spread function (ESF) (and hence MTF) results due to faulty re-projection. If this occurs, reduce the size of the re-projection region (try progressively smaller regions: 40 × 40 mm, 30 × 30 mm, etc.).
5. **sub_pixel size**: Enter the subpixel binning factor (0.1 usually gives a good result) (see Samei et al.[1] for definition). Essentially, large subpixels give reduced noise at the expense of resolution and vice versa.
6. The MTF must be calculated for the vertical and horizontal directions across the detector. The default for the program is to calculate the 'horizontal' MTF – labelled the '*u*' direction from now on. The user must examine the image to see which direction this actually is for the detector (images from a rectangular detector usually load in portrait orientation).
7. For a 'horizontal' MTF, the edge must be (almost) vertical in the image, ie with a small angle of ~3° to the vertical (see figure below).
8. **VERT MTF**: For a 'vertical' MTF, check the 'VERT MTF' box. The edge must lie (almost) horizontally across the image, ie with a small angle of ~3° to the horizontal.
9. Enter the STP information (see section 3.2). This is essential for systems with a non-linear STP.
10. Click on the 'MTF' button.
11. The MTF ROI is initially centred on the image by the program.

12. Move the MTF ROI to the region of edge that you wish to use for the MTF calculation – <left-click> on the ROI and drag the ROI around the image. Note that the edge must be fairly central within the MTF ROI (see below for typical positioning).



13. When satisfied with the position, <right-click> to calculate the MTF.
14. The program extracts the MTF_ROI from the image and linearises the ROI PV data via the STP (resulting in an 'air kerma' or 'photon' image) – this is displayed in a window.
15. The MTF_ROI PV data are then differentiated across the edge and the position of the maximum value of each differential profile across the edge is stored.
16. A first order fit is applied to the maxima ($y=a+bx$) and the a and b coefficients are displayed on the OBJ_IQ_reduced_v2 panel, along with the angle of the edge in degrees. The angle is $a\tan(1/b)$.
17. The differentiated image is displayed in a window and then the line that indicates the edge is plotted from the above equation.
18. The oversampled ESF is created by re-projecting the PV data around the edge (see Samei et al.[1] for the method). The region used for the re-projection is displayed in the MTF ROI window.
19. The ESF is displayed in a window.
20. The ESF is then filtered with a median filter of length 5 pixels.
21. The line spread function (LSF) is obtained by differentiating the ESF and displayed in a window.
22. FFT(LSF) gives the MTF.
23. Typical screen output for an MTF calculation is shown on the next page:



3.7.2 MTF output

The program saves the following files in .csv format ('comma separated value' – using a comma as a field delimiter – usually just double click on the file to open the file in Excel).

Horizontal MTF (left to right across the loaded image):

```
MTF_file = 'MTFu_' + data_id + '.csv' – the re-binned MTF, full
frequency MTF, ESF and LSF
```

Vertical MTF (up–down direction in the loaded image):

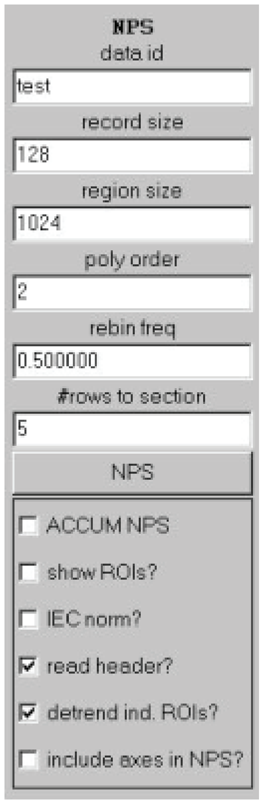
```
MTF_file = 'MTFv_' + data_id + '.csv' – the re-binned MTF, full
frequency MTF, ESF and LSF
```

Example

	A	B	C
1	Samei reprojection with Median filter = 5		
2	MTF region coords		
3	cols across image(x)=	1023.54	
4	rows up(y)=	1270.13	
5	y=a+bx		
6	a=	159.626	
7	b=	-17.419153	
8	angle=	-3.2856366	
9	Sub_pixel_size=	0.1	
10	Pixel size=	0.1988	
11	freq res of MTF=	0.049203564	
12			
13	freq(u)	MTF(u)	
14	0.000	1.000	
15	0.049	0.988	
16	0.098	0.972	
17	0.148	0.966	
18	0.197	0.953	
19	0.246	0.937	
20	0.295	0.925	
21	0.344	0.906	

3.8 Noise power spectrum (NPS)

3.8.1 Calculation steps for the NPS



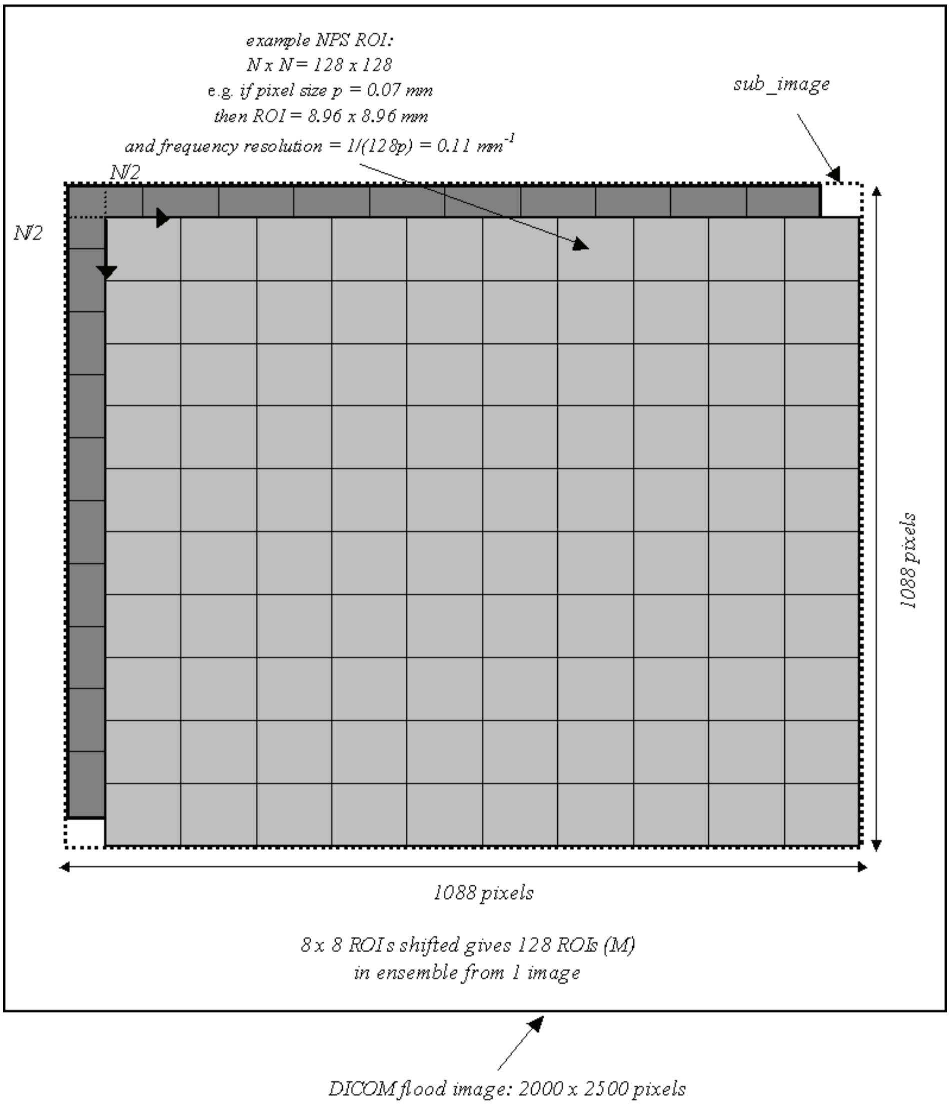
It is recommended that the data_id, record size, region size, polynomial order, rebinning frequency and number of rows out from the axis to section are set using the config.txt file.

1. Enter the correct STP information (see section 3.2). Select the normalisation type required: IEC (PV vs. Q) or direct NNPS (PV vs. K_a). This is essential – an accurate NPS cannot be calculated without this.
2. **data_id**: enter an appropriate label for ‘data_id’ (eg Rm2_5mAs).
3. **record_size**: enter the NPS record size (ie the size of the ROI that will be Fourier transformed in the NPS calculation) – this must be a power of 2, eg 128 or 256 (ie 2^7, 2^8, etc.). This is usually termed N in most NPS algorithms, and a common value is $N = 128 \times 128$. The record size governs the frequency resolution of the NPS; small records will tend to underestimate low frequency components of the NPS.
4. **region_size**: Enter the NPS region size – the size of the *sub_image* extracted from the DICOM flood image, from which the NPS ROIs are taken. Note that the program is currently set to use half-overlapping ROIs (records) and therefore for $N = 128$ and region size = 1024, *sub_image* = 1088 × 1088. Region size must be of size 2^n – typically 512, 1024 or 2048. Be careful when using large NPS region sizes as the image statistics may not be shift invariant/stationary over large areas. Using a larger NPS region will increase the number of ROIs

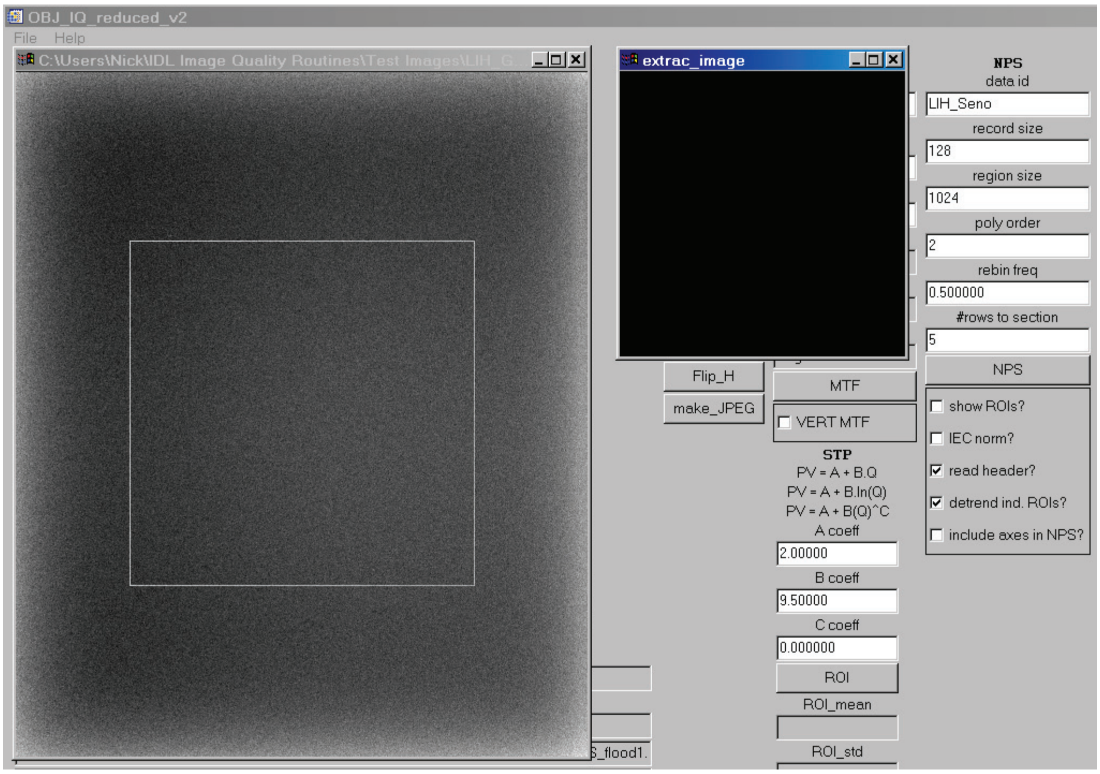
in the NPS ensemble (for a fixed ROI size) and this will reduce the statistical uncertainty on the NPS estimate. Dobbins et al.[2] show how the uncertainty on the NPS can be calculated.

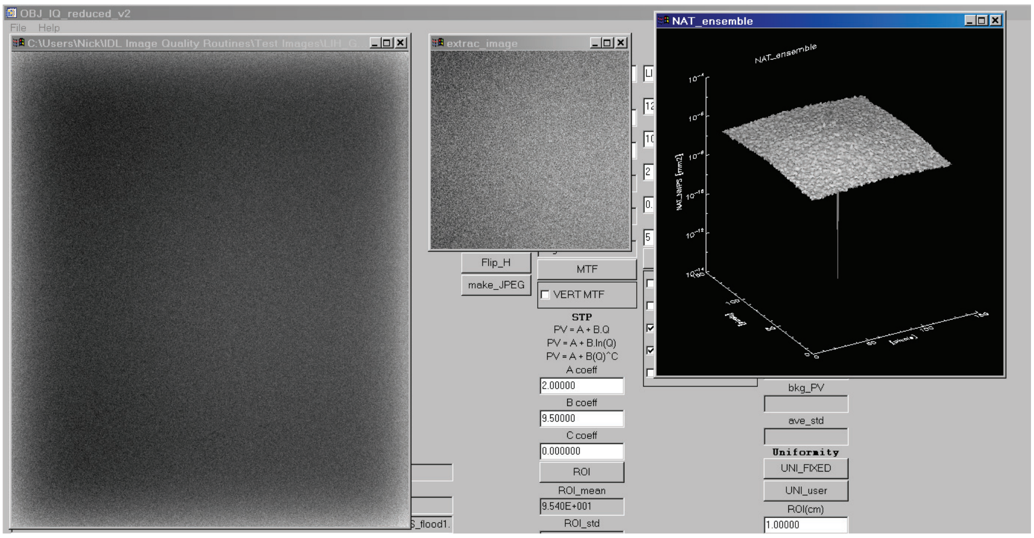
5. **poly order**: enter the polynomial order used for NPS ROI de-trending. This will influence the structured noise and low frequency content present in the NPS. A common value for polynomial order is 2.
6. **rebin freq**: enter the NPS re-binning frequency. The full frequency NPS is automatically saved.
7. **#rows to section**: enter the number of rows to section from the *u* and *v* axes.
8. **shows ROIs?**: select whether you want to show ROIs during the NPS calculation. This is useful for the first time through NPS to see which region of the image is being used for the NPS calculation. The program is significantly slower with this option on.
9. **IEC norm?**: check this box when you want to use the IEC conversion to photons (see section 3.2) – the default is to use an air kerma STP.
10. **detrend ind. ROIs?**: select whether you want to detrend individual NPS ROIs or apply the surface fit just to the *sub_image.*
11. **include axes in NPS?**: select whether you want to include the NPS from the $u = 0$ and $v = 0$ axes in the sectioned NPS.
12. Both ROI detrending and the inclusion/exclusion of the axes will again influence quantity of structured noise present in the NPS.
13. Once all the options have been set/selected press <NPS>.
14. The program will ask for the flood images (uniformly exposed) from which the NPS will be calculated. Multiple images can be selected by holding <Ctrl> and then clicking on the files. Note that the *sub_image* from which NPS is calculated is offset by $N/2$ in the *x* and *y* directions so that fresh fixed pattern noise is added in to the NPS estimate. Using a large number of images (say, nine) will mean that the required *sub_image* size may be larger than the images – the program will ask for a smaller *region_size* and/or smaller *ROI* size.
15. The program places the NPS *sub_image* ROI at the centre of the image.
16. <left-click> on the *sub_image* ROI and drag to the position in the flood image where you wish to calculate the NPS (mostly, just leave this ROI at the image centre).
17. <right-click> to calculate NPS.
18. A fuller explanation of the NPS algorithm is given in Marshall.[3] Some NPS, MTF and DQE results acquired in a QA setting for a range of FFDM units are given in Marshall.[4] As can be seen above, a number of parameters have to be chosen, and these all influence the measured NNPS to some degree. Please consult the general literature on this topic (including the forthcoming Report 32 Part vii *Measurement of the Performance Characteristics of Diagnostic X-Ray Systems: Digital imaging systems* by the Institute of Physical Sciences in Medicine[5]).
19. If using STP versus air kerma normalisation method: the normalisation of NPS is achieved by dividing by the (average PV)^2 of the image region from which NPS was extracted, ie by (image air kerma)^2. This will automatically give the normalised NPS (NNPS). However, if the dosimetry is wrong, then the NNPS will not be correct.

Definition of *sub_image* extracted from the DICOM flood image and the NPS *ROI* extracted from the *sub_image* (this example is for a general diagnostic detector):

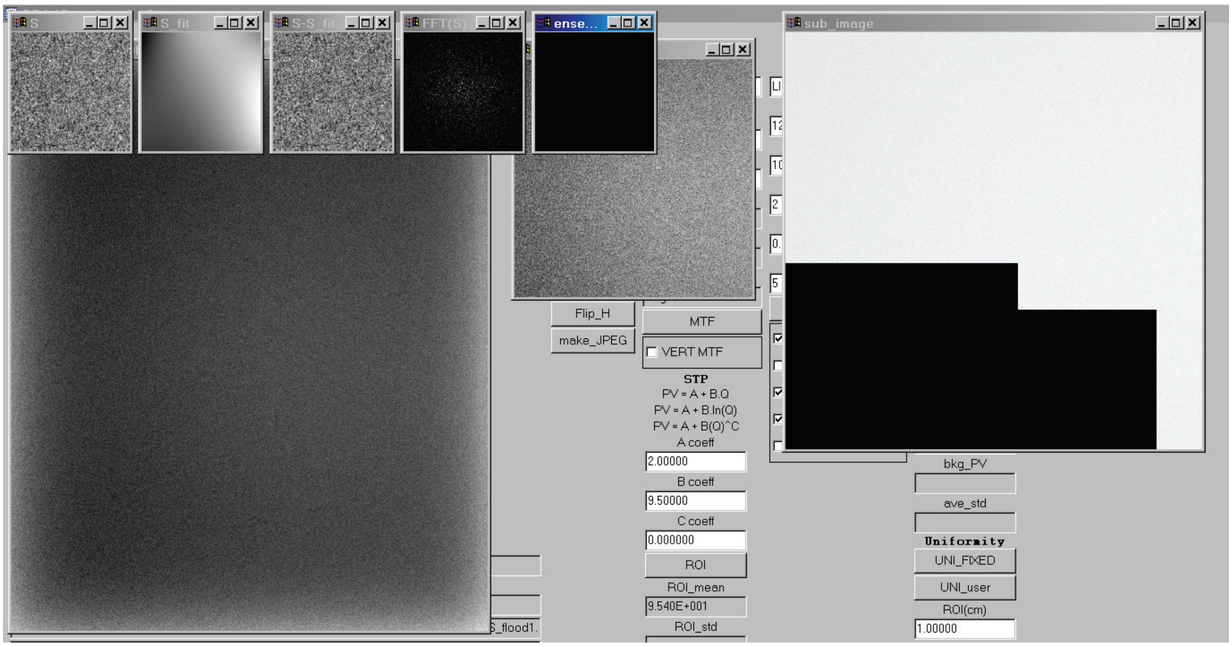


Select *sub_image* region for NPS calculation:





Typical output screen of the NPS program (with 'show ROIs' button checked):



3.8.2 NPS output

The following files are saved for NPS calculated from a single flood image:

The NPS ensemble with spatial frequency for plotting as a 3-D image of the NPS (import into a graph plotting program to do this):

```
ensemble_file = '3Dens_' + data_id + '.csv'
```

Example

u	*v*	NNPS (*u*,*v*)
-5.31401	-5.31401	7.2461102e-007
-5.31401	-5.23098	8.0436010e-007
-5.31401	-5.14795	8.2092825e-007
-5.31401	-5.06492	8.4003209e-007
-5.31401	-4.98188	7.5921367e-007
-5.31401	-4.89885	7.3717454e-007
-5.31401	-4.81582	7.5005044e-007

etc.

The NPS result as a .csv file:

```
NPS_file = 'NPS_' + data_id + '.csv'
```

The various NPS data are saved as follows:

Re-binned NPS:

sectioned '*n*' rows out from both sides of the *u* and *v* axes
sectioned at 45º and radially

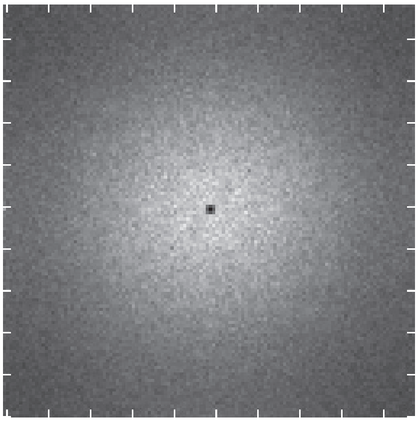
Full frequency NPS:

NPS sectioned '*n*' rows out from both sides of the *u* and *v* axes with no re-binning, eg

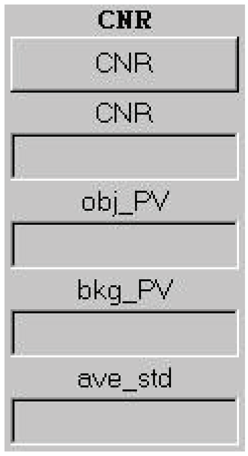
	A	B	C	D
1	Tue Apr 14 11:04:57 2009			
2	NPS coords			
3	NPSx=	829		
4	NPSy=	1019		
5	STP conversion=(image-A)/B)			
6	A=	0.000000 B=	1.00000 C=	0
7	NNPS normalized using Large Area Signal (LAS)			
8	image	PV_BC	var_BC	
9	1	907.258	276.067	
10	2	907.258	276.067	
11	image	PV_AC	var_AC	
12	1	907.258	276.067	
13	2	907.258	276.067	
14	NPS_Region size=	1024		
15	N_(ROI)=	128		
16	M=	256		
17	#_images	2		
18	poly=	2		
19	dx=	0.0940909		
20	freq_res=	0.0830314		
21	excluding v=0 and v=0			
22	rebinning_freq=	0.5		
23	#NPS_rows_sectioned_out_from_axes=	5		
24	rebinned axial NPS			
25	u_rebin	NAT_NPS(u)	v	NAT_NPS(v)
26				
27	0.49077931	3.56E-06	0.49077931	3.58E-06
28	0.99543738	3.39E-06	0.99543738	3.41E-06
29	1.4955902	3.13E-06	1.4955902	3.07E-06
30	1.99562	2.81E-06	1.99562	2.73E-06
31	2.4980447	2.46E-06	2.4980447	2.41E-06
32	3.0018404	2.07E-06	3.0018404	2.08E-06
33	3.5065498	1.88E-06	3.5065498	1.77E-06
34	4.0112467	1.63E-06	4.0112467	1.52E-06
35	4.5170512	1.50E-06	4.5170512	1.42E-06
36				
37	rebinned 45 degree and radial NPS			
38	u45	NAT_NPS45(u)	u_radial	NAT_NPSradial(u)
39				
40	0.48539609	3.58E-06	0.49886453	3.57E-06
41	0.9951703	3.39E-06	1.0129987	3.38E-06

The NPS ensemble is saved as a .jpeg:

```
ensemble_im = 'ens_im_' + data_id + '.jpg'
```



3.9 Contrast to noise ratio (CNR)



A routine to measure CNR. It is essential that the correct STP data are entered before using this routine.

The routine places an ROI on the image (the size of the ROI is taken from the non-uniformity ROI) – position this over the (contrasting) object and <right-click>. A second ROI is then placed on the image (at the location of the first ROI) – position this on a region of image background and <right-click>. The PV data in the two ROIs are linearised via the STP and the mean PV and variance are calculated. The CNR is displayed on the panel along with the mean PV for the object and background and the average standard deviation (ave_std).

The average standard deviation is sqrt((var_bkg + var_obj)/2) and CNR =abs(mean_bkg – mean_obj)/ave_std.

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6. Cranley K, Gilmore BJ, Fogarty GWA and Desponds L. *Catalogue of Diagnostic X-Ray Spectra and Other Data.* Institute of Physics in Medicine 1997 (IPEM Report 78).

APPENDIX 1: SUGGESTED READING

Books

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APPENDIX 2: SYSTEM DICOM FILES THAT HAVE BEEN USED WITH THIS PROGRAM

Please note systems used and any problems loading/reading the DICOM headers.

Hologic
Selenia FFDM
EPEX

GE
Senographe DS FFDM
AMX 700

Agfa

Shimadzu
Dart

Fuji
Fuji Profect CR

Siemens

Philips
PCR Corado

Toshiba
Infinix Cardiac System

APPENDIX 3: EXAMPLE OF WORKING ORDER WHEN MEASURING OBJECTIVE IMAGE QUALITY AS PART OF DETECTOR QUALITY ASSURANCE

This example is for a mammography detector. The principles are similar for general diagnostic radiography detectors, except that beam quality will be different (for example, the spectrum could be 70 kV and 1 mm added copper, as often specified in IPEM Report 91) and the air kerma range at the detector will be different (for example, from 0.5 μGy to 25 μGy).

Detailed list of steps involved:

1. Check that images to be acquired for the detector measurements have no additional spatial frequency processing such as edge enhancement, ie that they are 'for processing'. FineView and PremiumView should be disabled for GE systems.
2. Choose the beam quality – that is the tube potential, target and filter – that the system selects for 4.5 cm polymethylmethacrylate (PMMA) under automatic exposure control (AEC) using the most commonly used AEC mode. An example for the GE Senographe is 29 kV and Rh/Rh.
3. Suspend 4.5 cm PMMA at the tube exit port. Use the compression plate for additional support.
4. Protect the detector with a radio-opaque beam block.
5. Measure output/mAs at some FCD (focus–chamber distance) with the chamber placed at the standard distance (4 cm) from the chest wall (use at least three mAs values).
6. Calculate air kerma at detector as *fn* mAs. For example, for the GE Senographe:

$$K = 3.089 \times \text{mAs} + 1.484 \quad (1)$$

7. Use this equation to calculate the mAs values needed for typical detector air kerma values, eg 12.5, 25, 50, 100, 200 and 400 μGy.
8. Remove the grid (use appropriate grid transmission factor in equation (1) if leaving grid in).
9. Set calculated mAs values and acquire the flood images over the air kerma range (these are referred to as the STP flood images).
10. Replace grid and acquire images for the non-uniformity tests (check flat fielding etc.). Acquire flood image at typical detector air kerma for all target/filter combinations used on the system. Set a typical tube potential, eg 28 kV.
11. Remove the PMMA from tube exit port.
12. Perform the ghosting test (image retention).
13. Place the MTF edge on the table top at the detector centre with slight twist to get a ~3° angle to pixel matrix. This will allow four MTFs to be calculated (although not the same point on the detector – this is QA). Acquire at least two MTF edge images in case one cannot be read. If you want to calculate the vertical and horizontal MTFs at similar positions on detector, acquire two images, shifting the edge between exposures to the same point on the detector.
14. Save images to a picture archiving and communication system (PACS), burn to CD or send to a USB drive, etc.
15. Find the relevant images (STP flood, non-uniformity and MTF edge images), rename them so that they are easily identified and save them to your QA image archive.
16. STP: measure PV at image centre and plot against air kerma at detector (calculated using equation 1). Fit the appropriate curve (linear, log, etc.) and note the fit coefficients. For example, for the GE Senographe:

$$\text{PV} = 11.8 \times K - 2.0 \quad (2)$$

17. Add the fit coefficients and STP type in the OBJ_IQ config file and save to the directory for the detector QA visit.
18. Set the re-binning frequency in the config file – typically use 0.5/mm for mammography, although 0.25/mm could be used.
19. Start OBJ_IQ_reduced, set the appropriate image and output directories and load the config file.
20. NNPS: Calculate NNPS for the chosen detector air kerma: at 100 µGy, for example. Note that this is a different approach from the detector reference air kerma used in the UK protocol (NHSBSP Report 0604) in which a typical PV for the AEC mode is chosen and the air kerma for this PV is calculated from the detector response (STP). Instead of this, we are setting an air kerma value and calculating NNPS at this air kerma – this will be done throughout the life of the detector to monitor changes at a given air kerma.
21. Non-uniformity: calculate non-uniformity for the *T*/*F* combinations.
22. MTF: Calculate MTF in the two detector directions.
23. NNPS and MTF should have the same re-binning. If this is the case then calculate DQE for the air kerma used:

$$\mathrm{DQE}(u) = \frac{\mathrm{MTF}^2(u)}{q_o\, K \cdot \mathrm{NNPS}(u)} \tag{3}$$

where q_o is the number of photons used per unit air kerma for the beam quality used (tube potential, target, added filtration thickness (Be, Mo, Rh, etc.), added beam filter such as 4.5 cm PMMA or 2 mm aluminium, target angle, waveform ripple) calculated using IPEM Report 78,[6] for example. *K* is the air kerma of the flood image from which the NNPS was taken.

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