United Lincolnshire Hospitals NHS
NHS Trust

Development and initial experience of a detectability index plugin for ImageJ

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Head and neck reconstruction filter

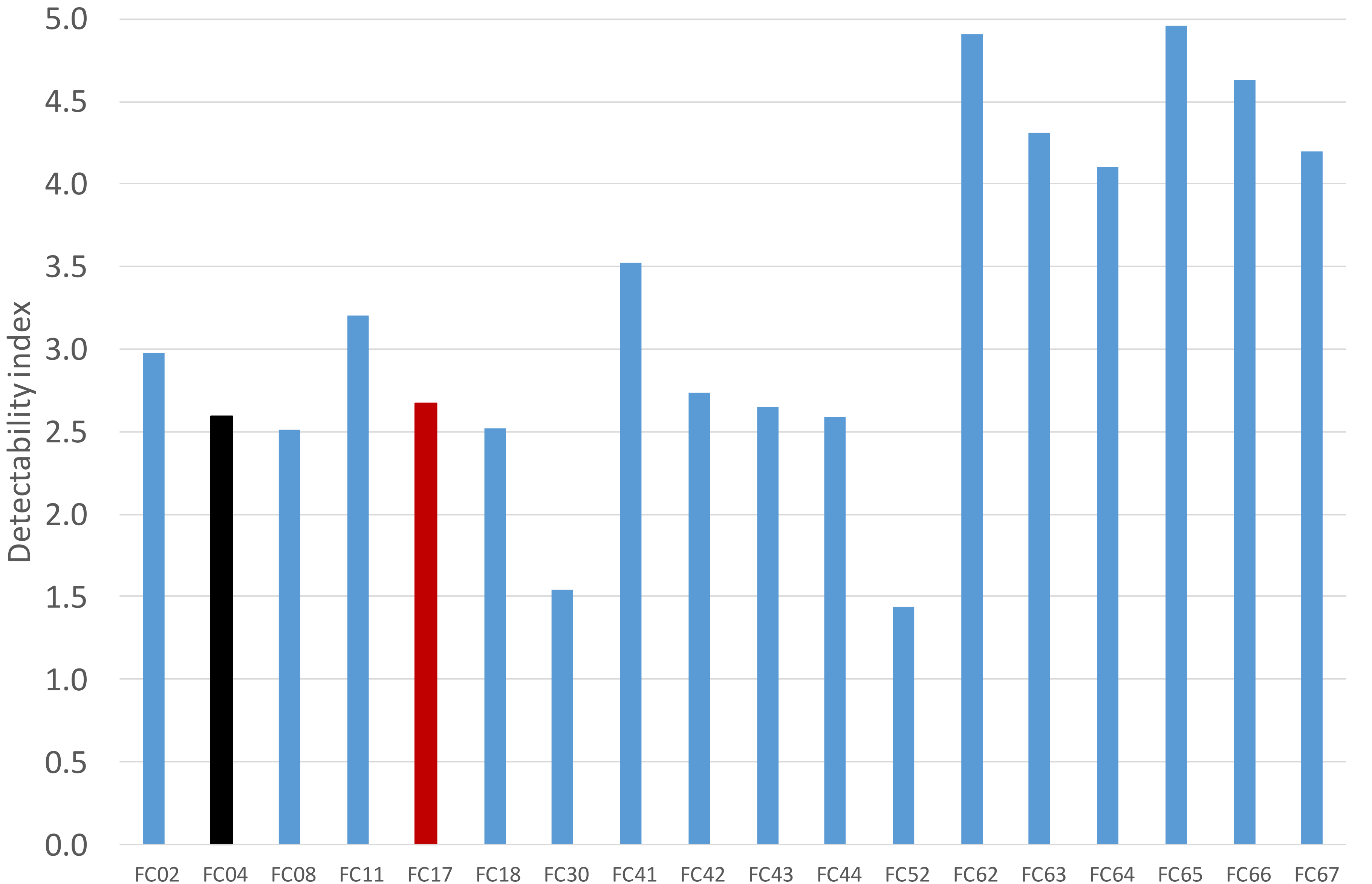
- Scanned Mercury 4.0 phantom[1] with clinical head and neck protocol
- Reconstructed with 18 different kernels
- Calculated detectability index (d’) for each reconstruction
- Compared the values of d’ for each kernel

Head and neck reconstruction filter

Filter	Clinical indication
FC02	Abdomen with beam hardening correction
FC04	
FC08	
FC11	Abdomen without beam hardening correction
FC17	
FC18	
FC30	Bone
FC41	Head without beam hardening correction
FC42	
FC43	
FC44	
FC52	Lung
FC62	Head with beam hardening correction
FC63	
FC64	
FC65	
FC66	
FC67	

Parameter	Value
Phantom section diameter	21 cm
Insert material	Polystyrene
Insert contrast (HU)	50
Simulated object diameter (mm)	5
Task function type	Disc
Image slices used for TTF calculation	66 – 76
Image slices used for NPS calculation	84 – 88
Eye model	Solomon et al. 2015

Head and neck reconstruction filter



Threshold contrast detectability

- Objects of a certain size and contrast
- Spatial resolution
- Noise
- Human observer

Detectability index (d')

$$d'^2 = \frac{\left[\int_0^{f_N} |W(f)|^2 . TTF^2(f) . E^2(f)\, df\right]^2}{\int_0^{f_N} |W(f)|^2 . TTF^2(f) . NPS(f) . E^4(f)\, df}$$

where

- f is radial frequency
- W(f) is a task function, the Fourier transform of the signal to be detected (object of a certain size and contrast)
- TTF(f) is the task transfer function (spatial resolution)
- NPS(f) is the noise power spectrum (noise)
- E(f) is the frequency response of a model of the human eye (human observer)
- f_N is the Nyquist frequency calculated from the image pixel size

d' is a non-prewhitening with eye filter (NPWE) model observer adapted from 2

Model observers similar to this have been shown to strongly correlate with:

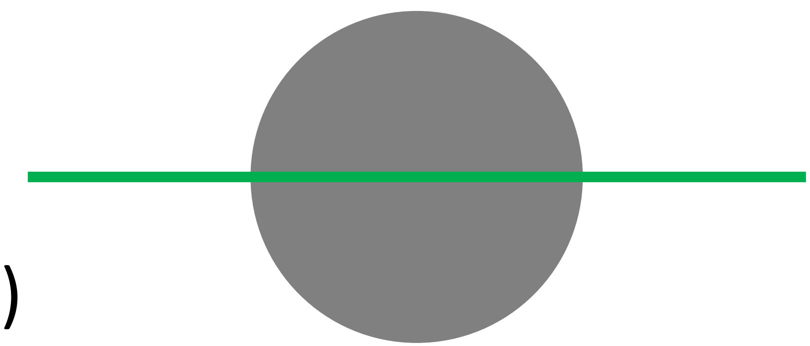
- human performance [3, 4, 5]
- threshold contrast in mammography and general radiography [6, 7]

Other software for d’ calculation

- imQuest software[8] is available to calculate d’ from images of the Mercury 4.0 phantom
  - Pre-compiled Matlab application
  - Source code also now available
- Issue with repeatability of d’ calculation in pre-compiled version 7.0 of imQuest
  - Has been fixed in source code version
- Eye model and task function component results not readily available to the user
- Manual positioning of individual NPS regions

Task function, W(f)

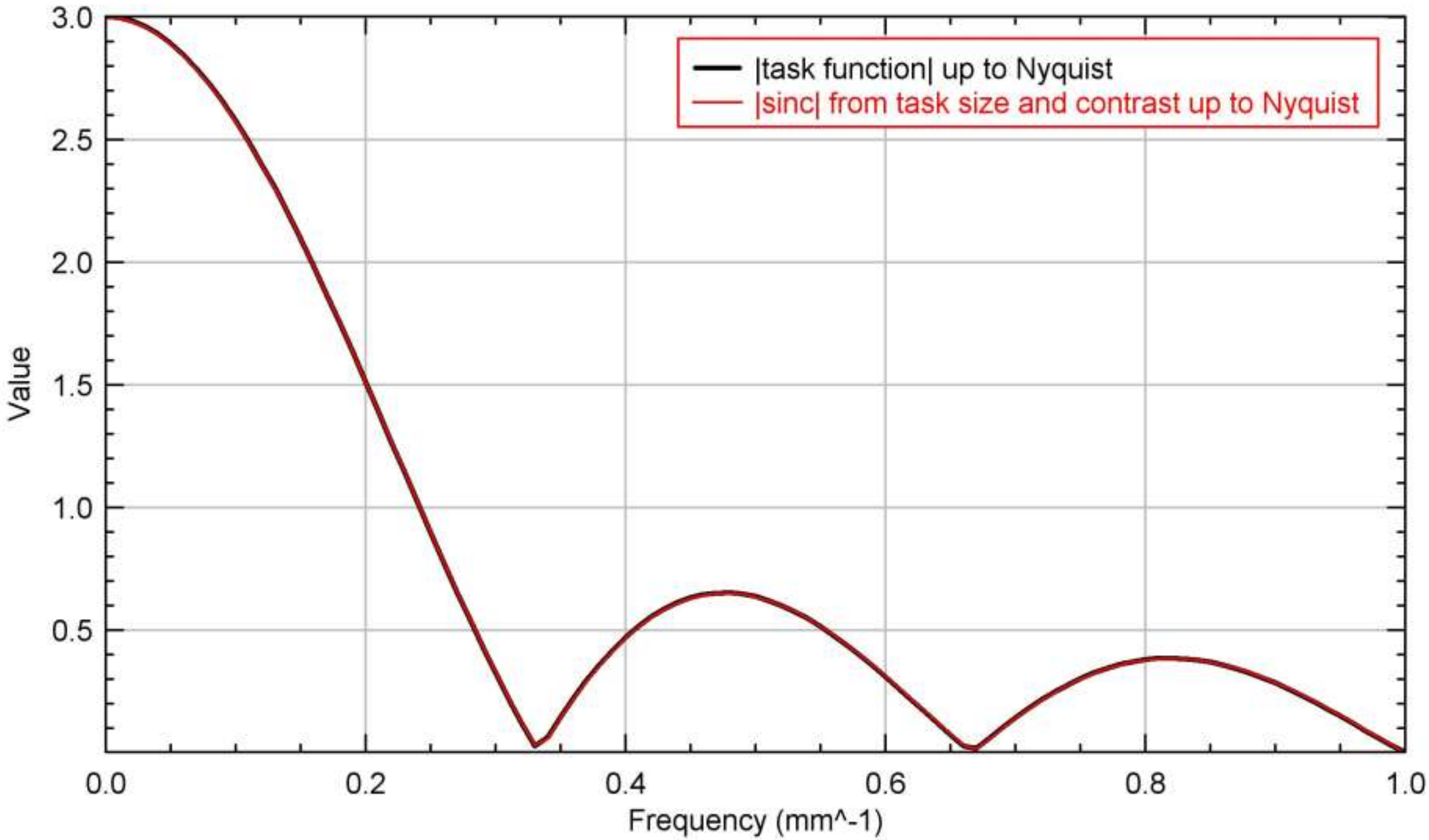
- The Fourier transform of the signal to be detected
- Signal is a "perfect" circular image that would result from CT scanning an infinite cylinder
  - specified diameter, d
  - specified contrast, c



- Has radial symmetry (a circle)
- "Top-hat" in cross-section

- Fourier transform of a top-hat function is a sinc function with maximum value = c.d [9]

Task function, W(f)



Eye function, E(f)

- Simple model incorporating the frequency response of the human eye; several versions [2, 3, 4, 10]

Eye function, E(f)

Solomon et al [2] use:

$$E(\rho) = \left|\eta . \rho^{a_1} . e^{-a_2 . \rho^{a_3}}\right|^2$$

where

- ρ is angular spatial frequency (deg^{-1})
- a_1 = 1.5; a_2 = 0.98; a_3 = 0.68
- η is a factor to set $E(\rho)_{max}$ to 1.0

Eye function, E(f)

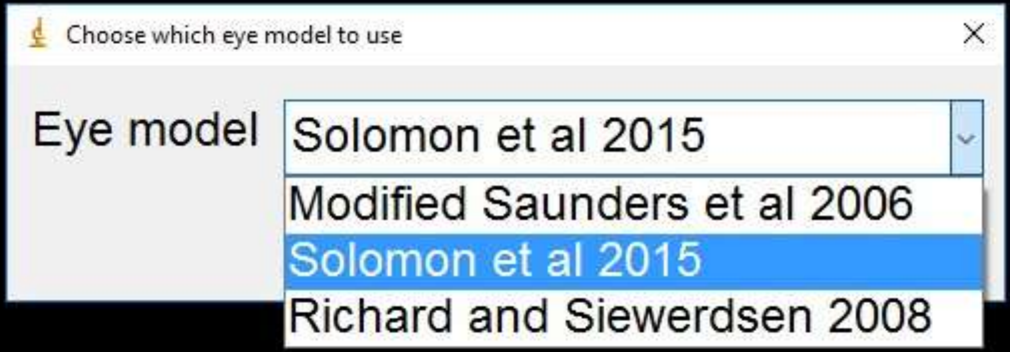
Angular spatial frequency (ρ) calculated using:

$$\rho = f \times \frac{FOV.R.\pi}{D.180}$$

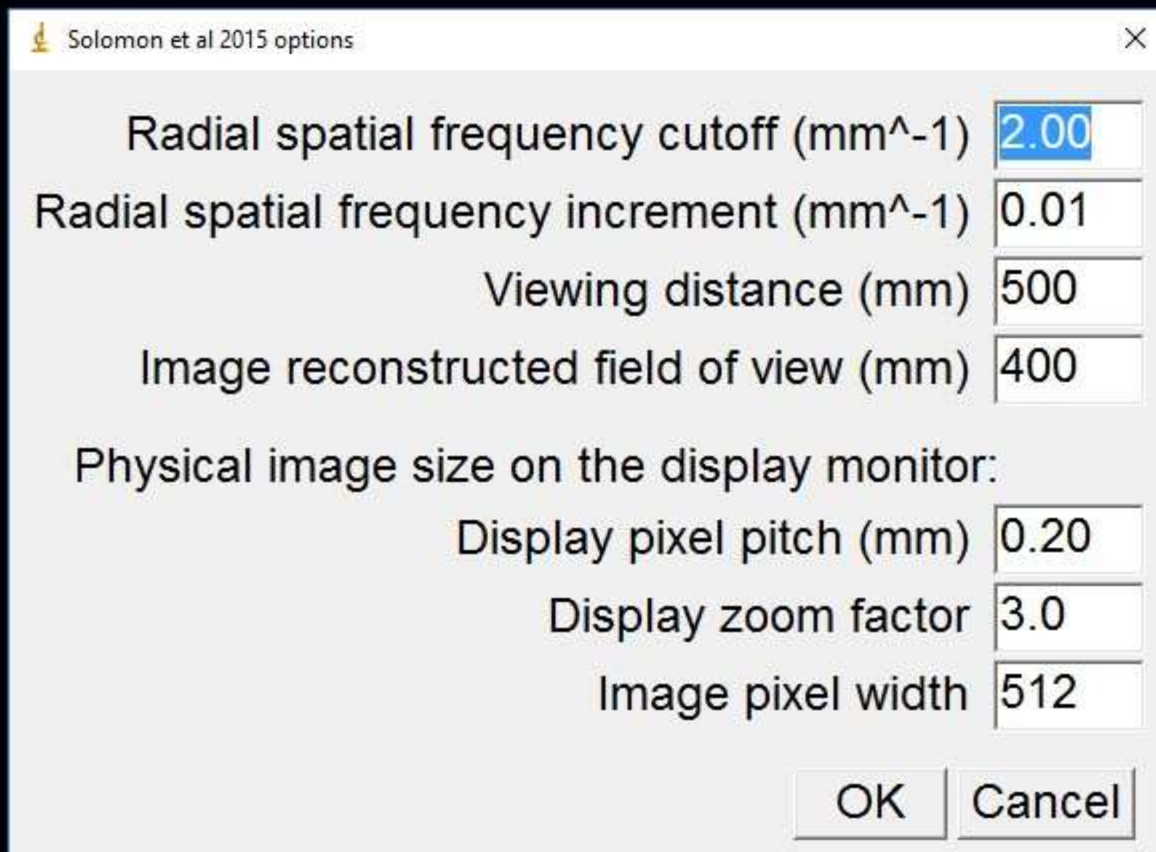
where

- f is radial spatial frequency (mm^{-1})
- FOV is the reconstructed field of view of the image (mm)
- R is the viewing distance (mm)
- D is the size of the displayed image on the screen (mm)

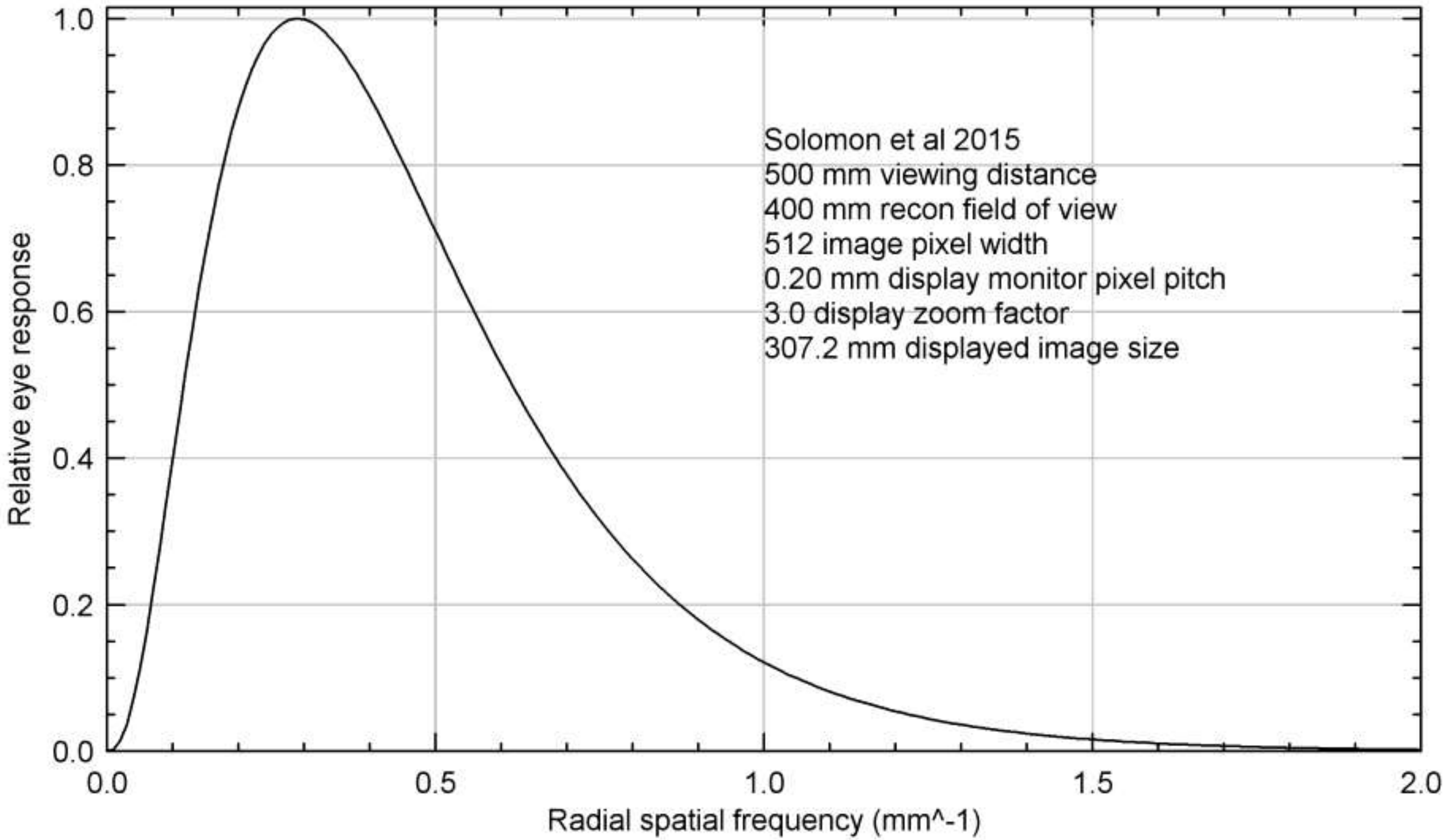
Example eye function, E(f)



Example eye function, E(f)



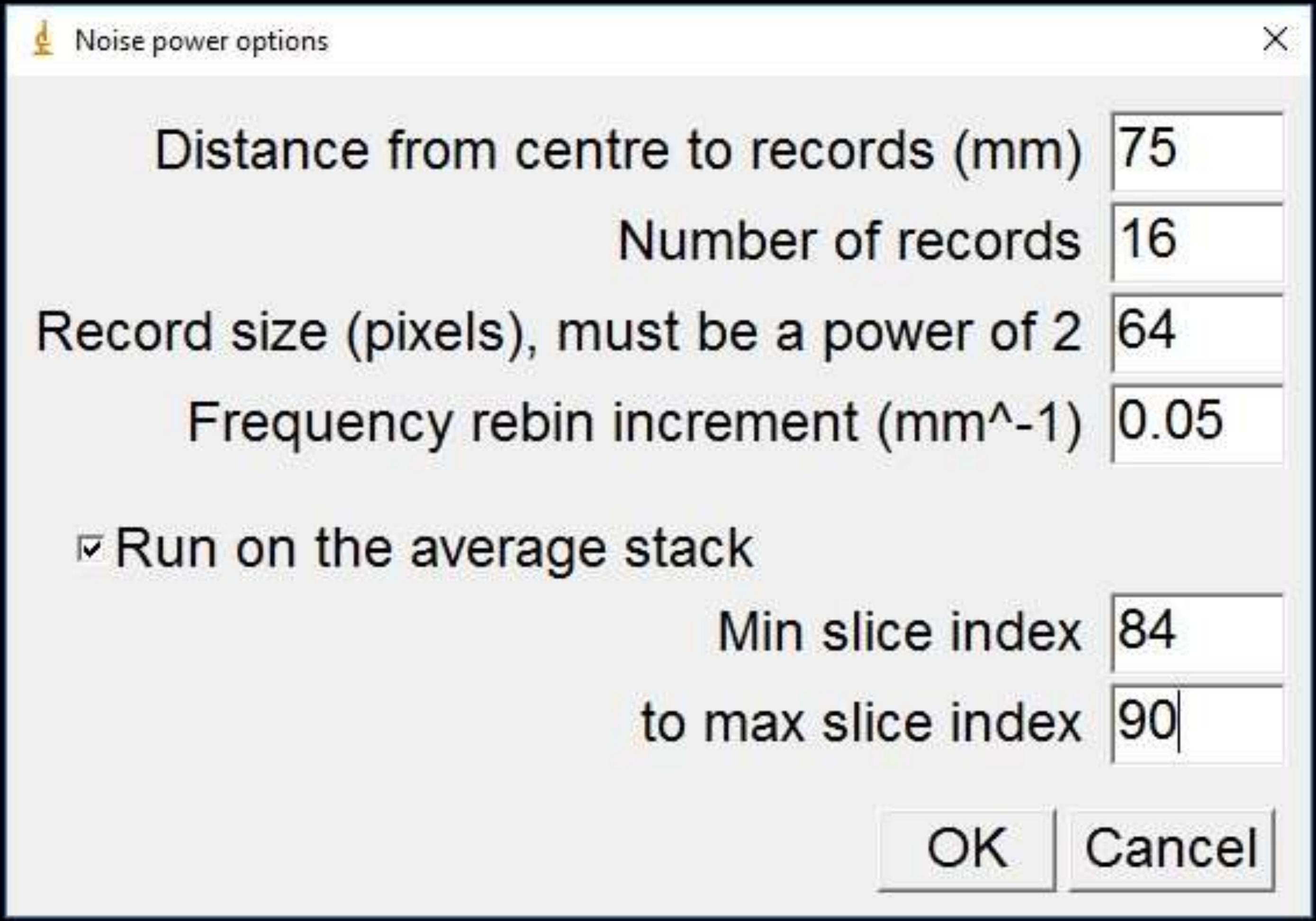
Example eye function, E(f)



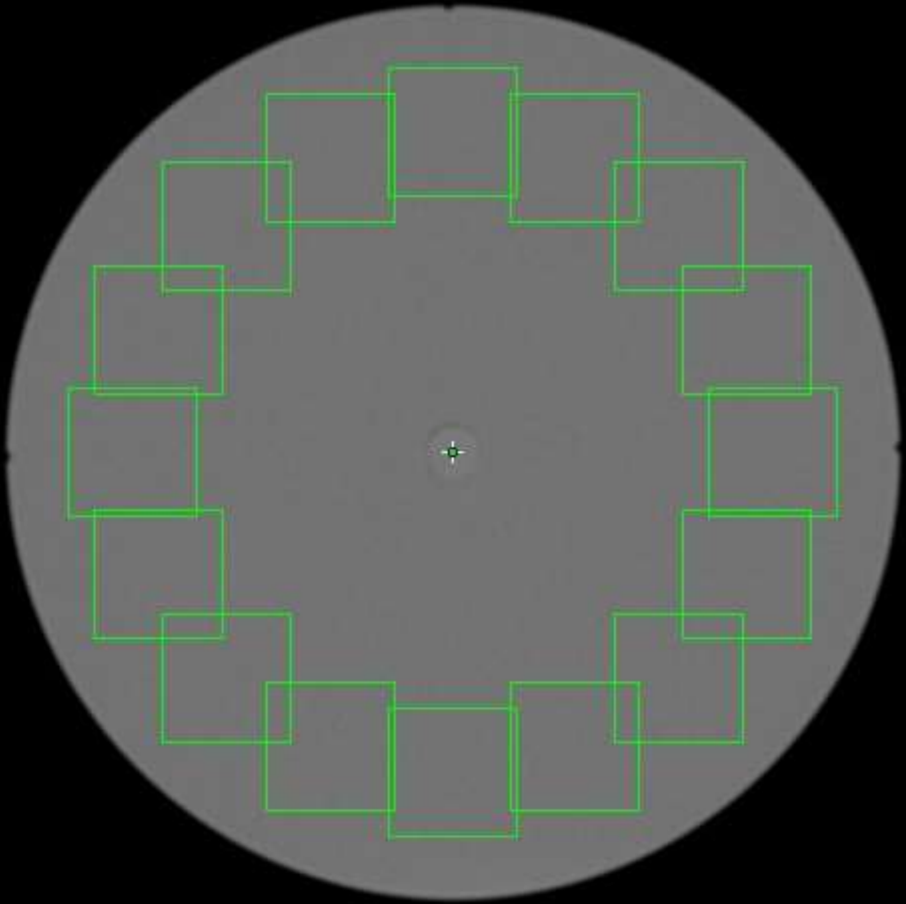
Noise power spectrum, NNPS (f)

- Calculated from a number of square "records" positioned a specified radial distance from the centre of an ROI or the whole image
- 2D version of ICRU 87 method [11]
- Configurable:
    - Number of records
    - Size of records
    - Radial distance
    - Number of images to use

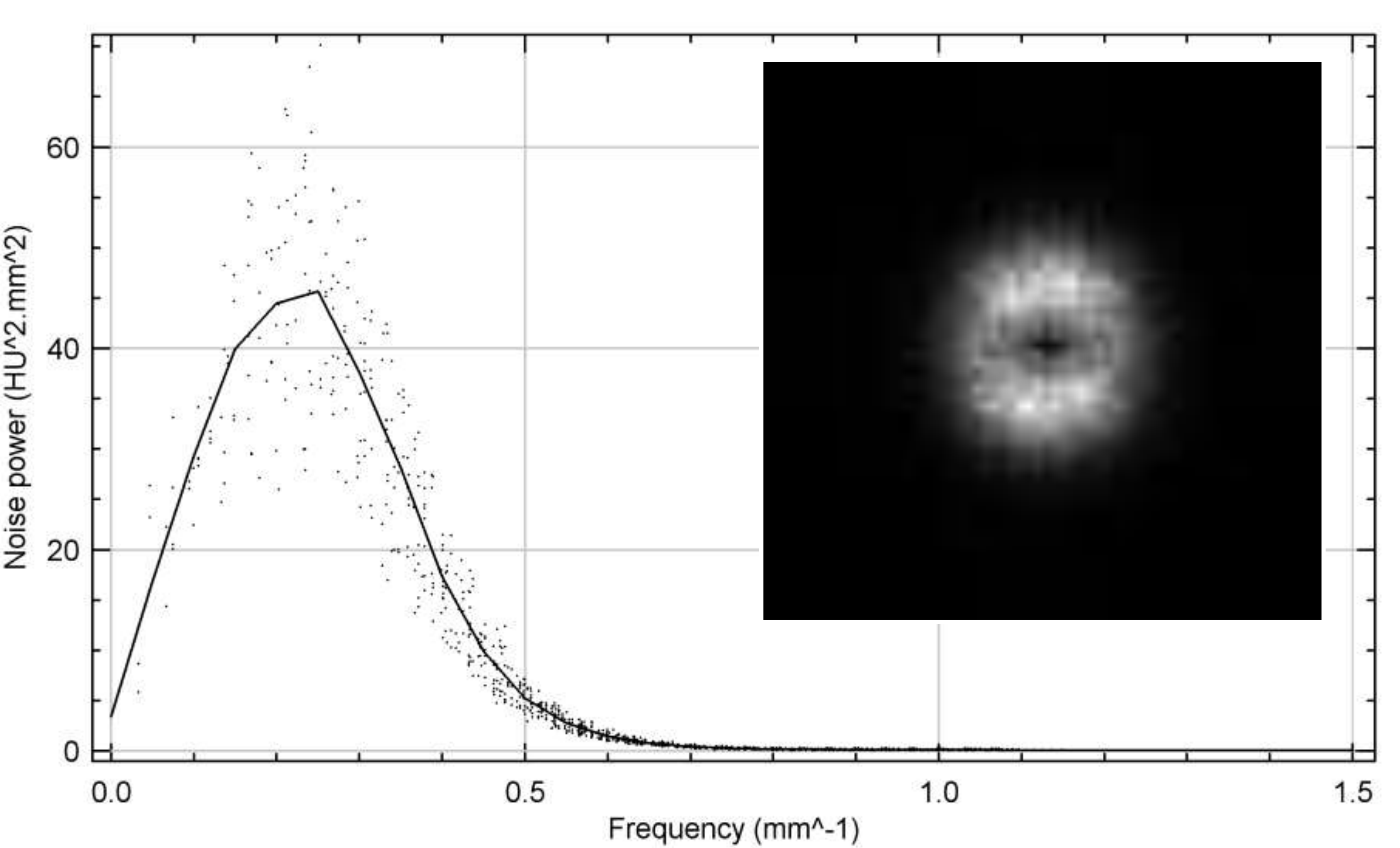
Noise power spectrum, NNPS (f)



Noise power spectrum, NNPS (f)



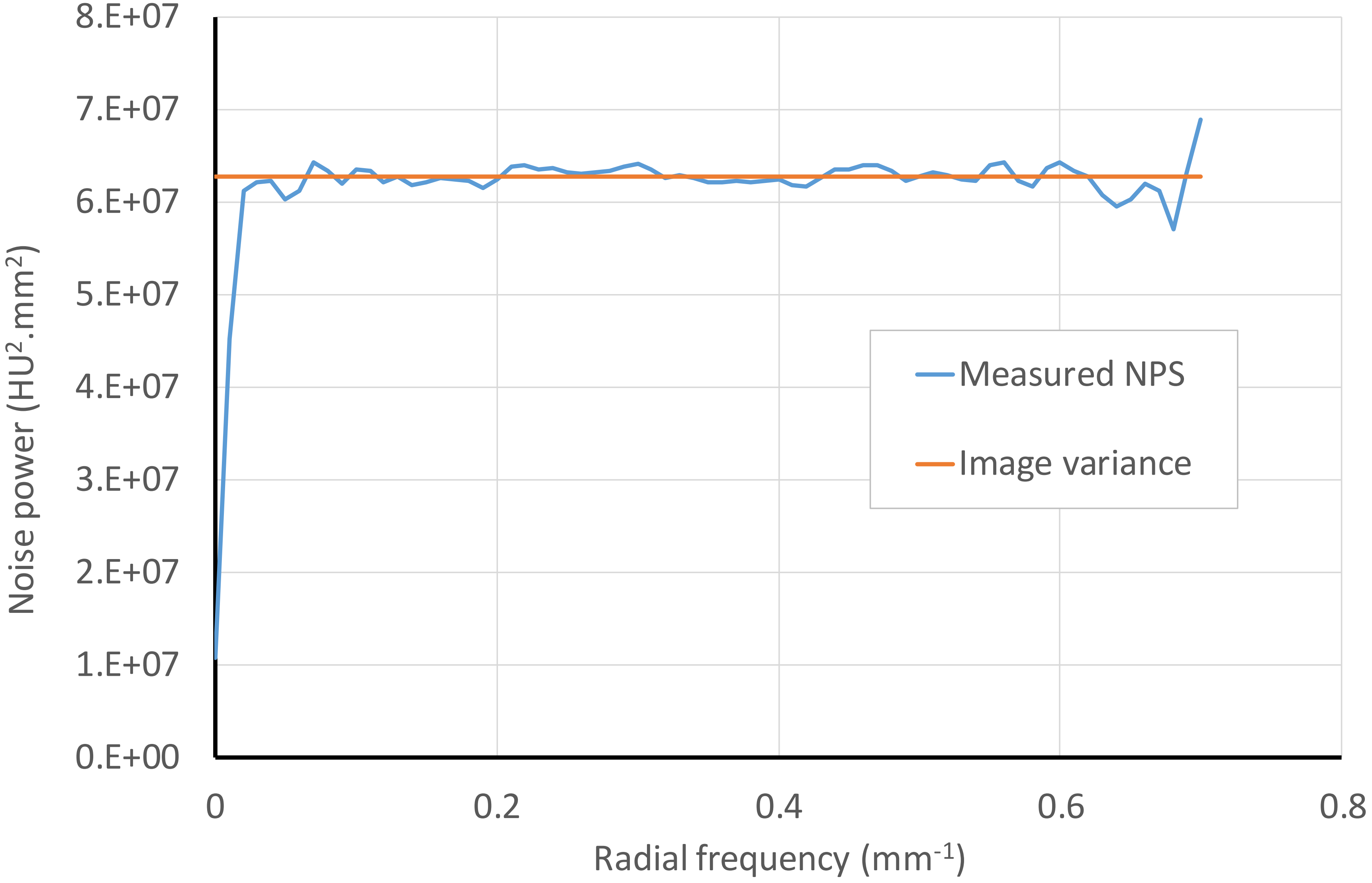
Noise power spectrum, NNPS (f)



Noise power spectrum, NNPS (f)

- Validation
  - Random noise image created in ImageJ
  - 1024 x 1024; 1 mm pixel size
  - Ran NPS plugin (32 records, 128 pixel record size, 350 mm record radius)
  - Measured the variance of the image
  - Noise power should be equal to variance

Noise power spectrum, NNPS (f)

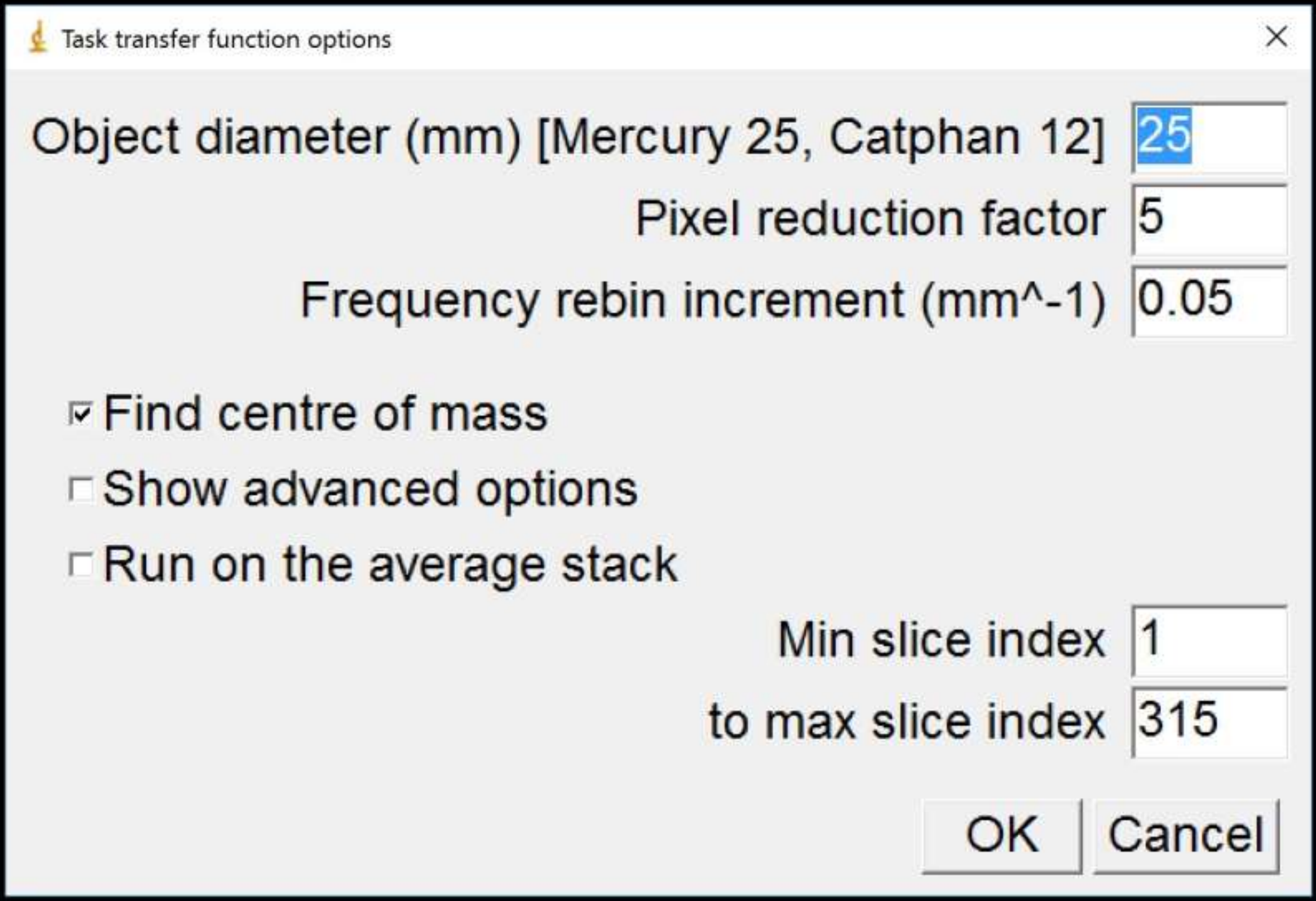


Task transfer function, TTF(f)

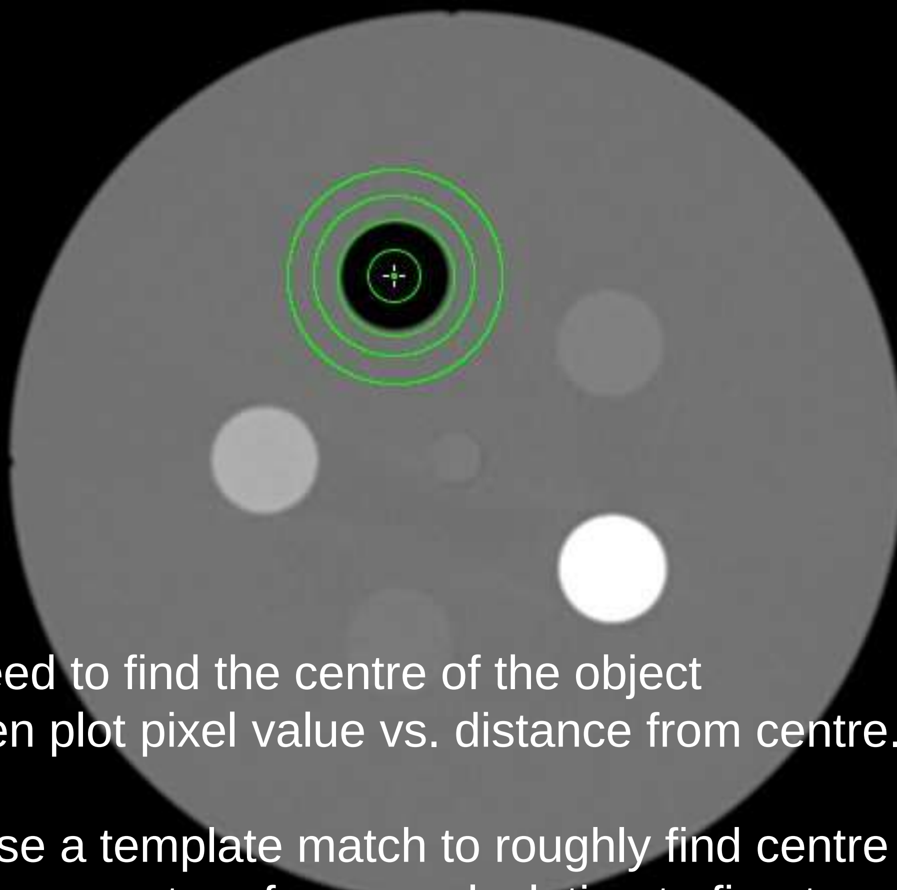
- Similar to the modulation transfer function (MTF) but suited to non-linear systems that may depend on the imaging task [12]

- Fourier transform of the line-spread function of an object with a certain contrast and noise

Task transfer function, TTF(f)



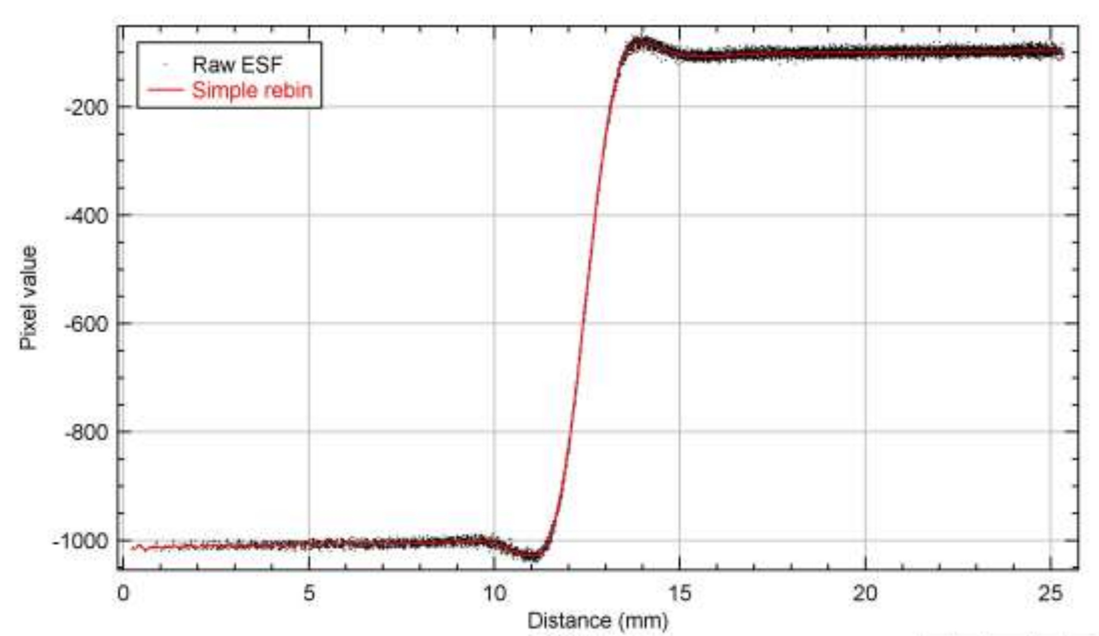
Task transfer function, TTF(f)

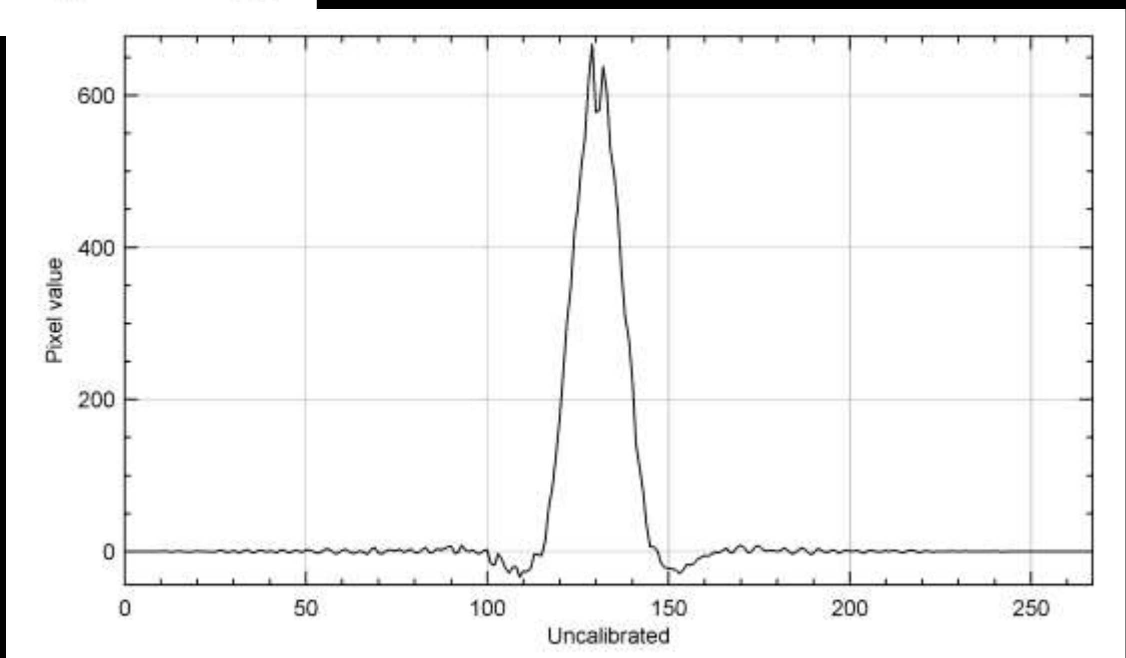


Need to find the centre of the object
then plot pixel value vs. distance from centre.

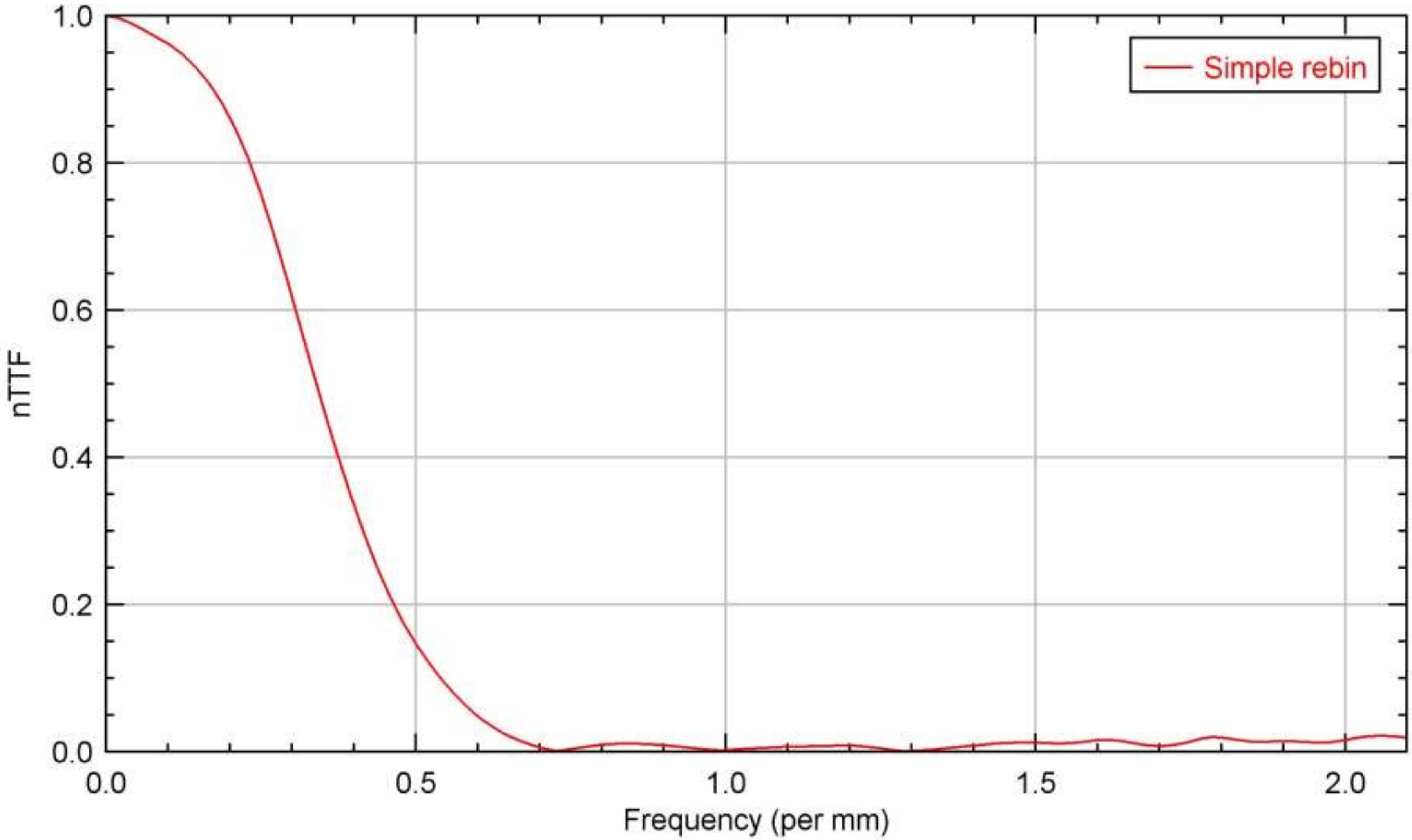
I use a template match to roughly find centre
then a centre of mass calculation to fine-tune

Task transfer function, TTF(f)





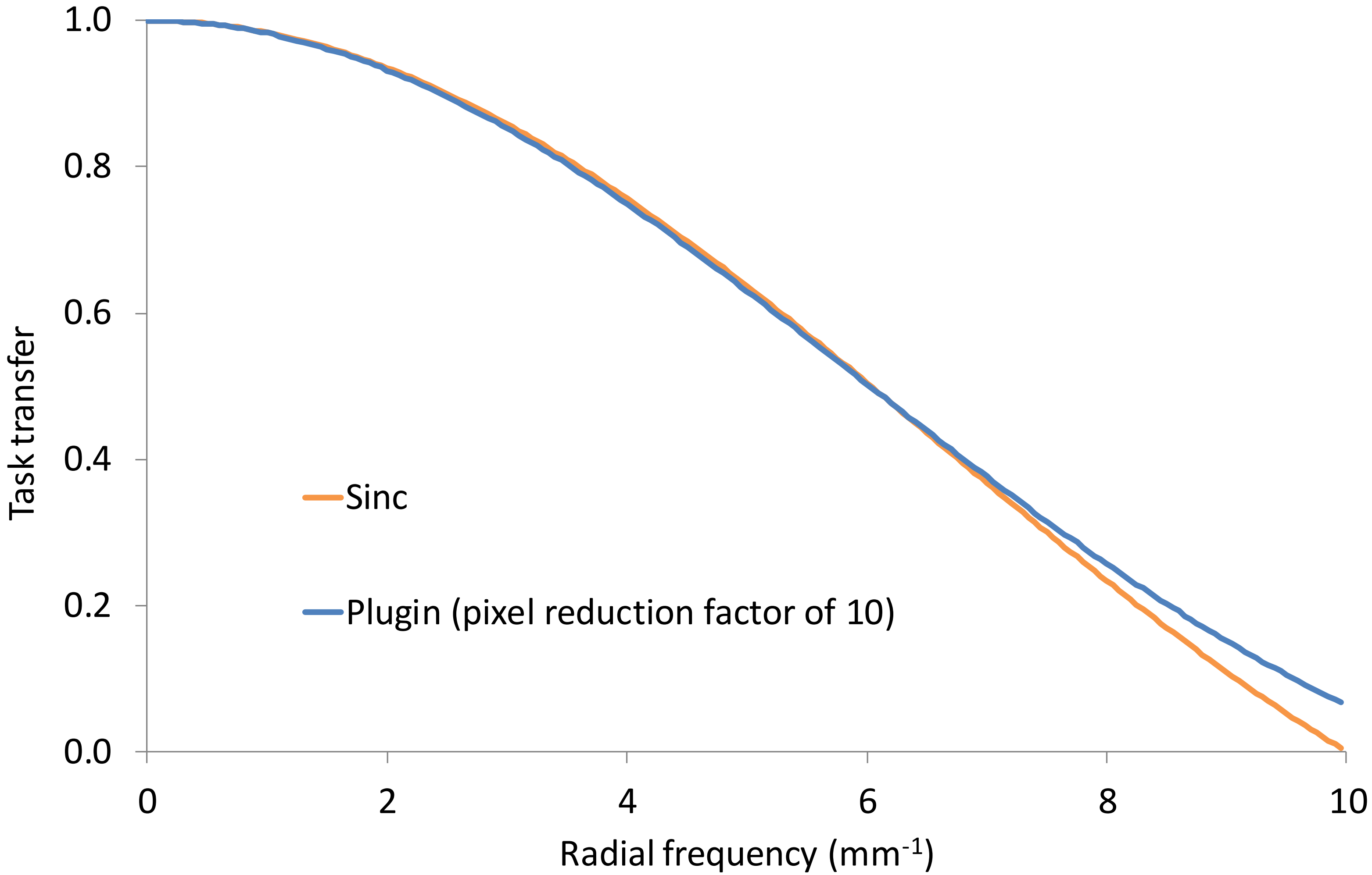
Task transfer function, TTF(f)



Task transfer function, TTF(f)

- Validation
  - Creation of a “perfect” test image
  - Should have a TTF equal to the sinc function calculated from the image pixel size

Task transfer function, TTF(f)



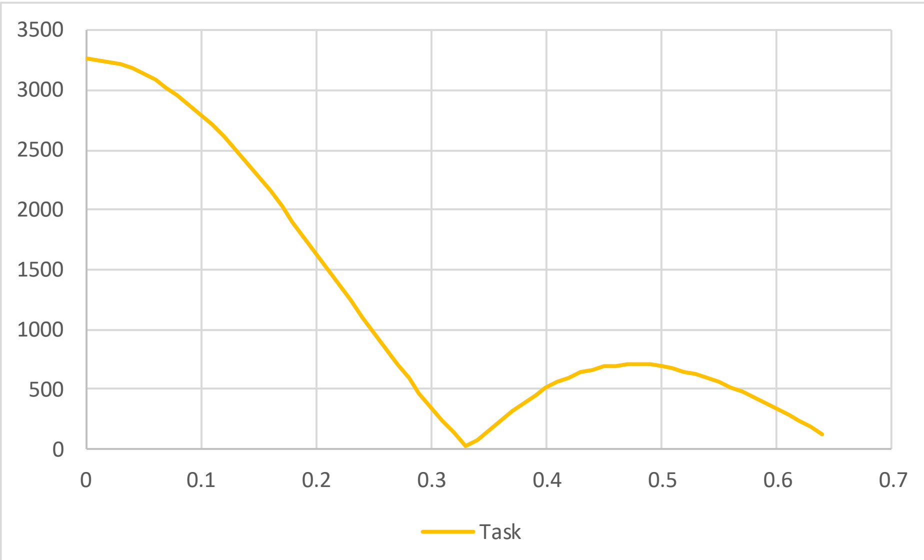
Calculation of d'

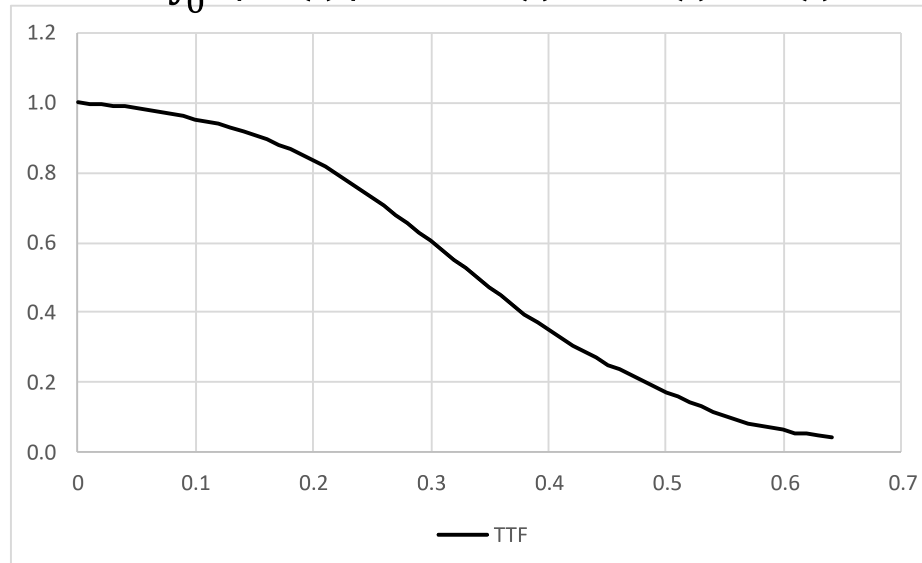
- Multiply the components together and integrate over radial frequency as per:

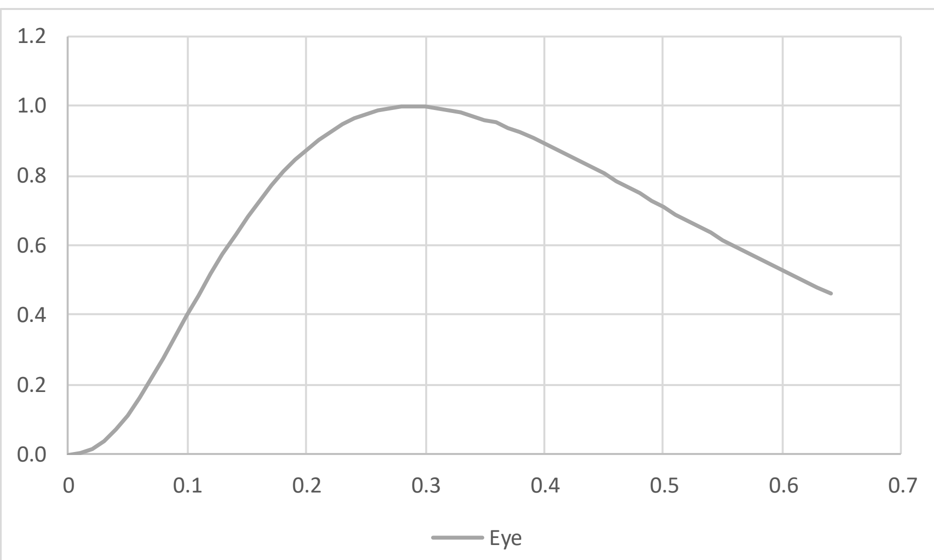
$$d'^2 = \frac{\left[\int_0^{f_N} |W(f)|^2 . TTF^2(f) . E^2(f)\, df\right]^2}{\int_0^{f_N} |W(f)|^2 . TTF^2(f) . NPS(f) . E^4(f)\, df}$$

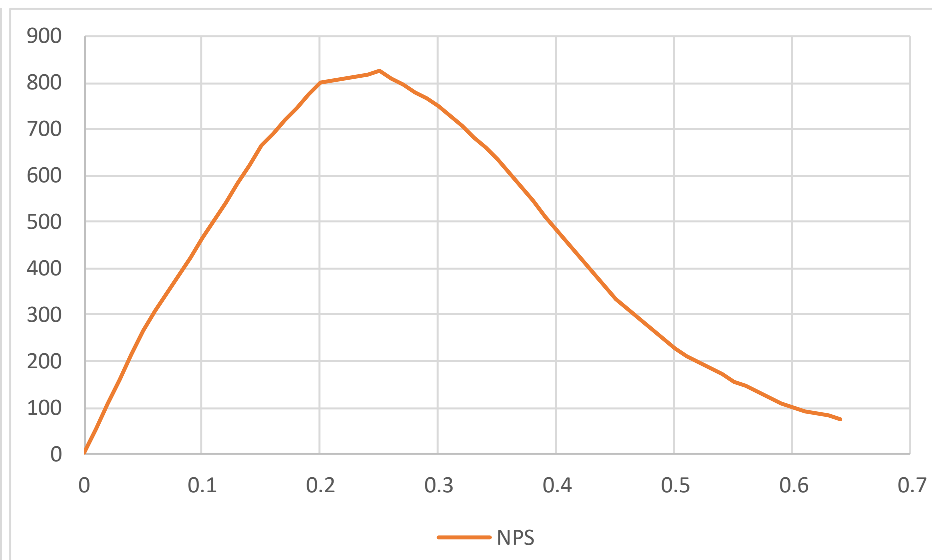
Calculation of d'

$$d'^2 = \frac{\left[\int_0^{f_N} |W(f)|^2 . TTF^2(f) . E^2(f)\, df\right]^2}{\int_0^{f_N} |W(f)|^2 . TTF^2(f) . NPS(f) . E^4(f)\, df}$$



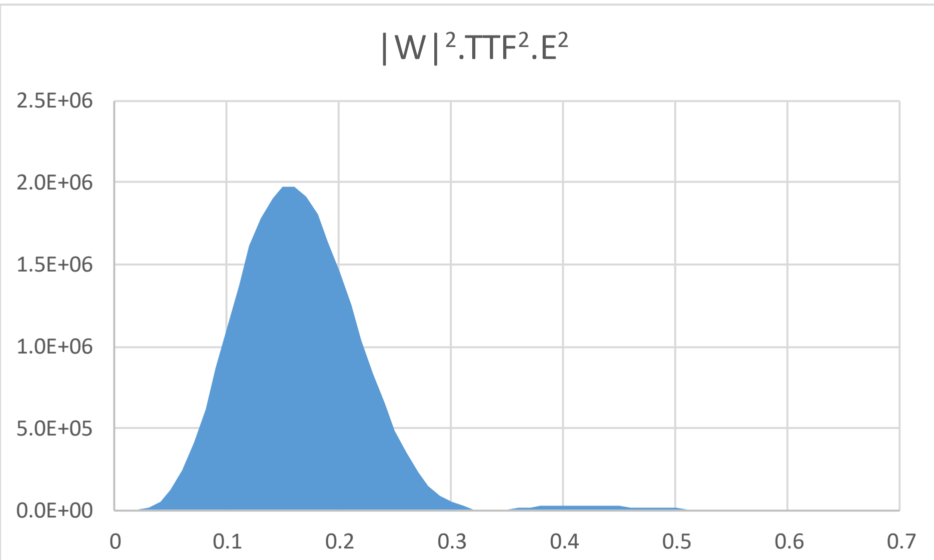


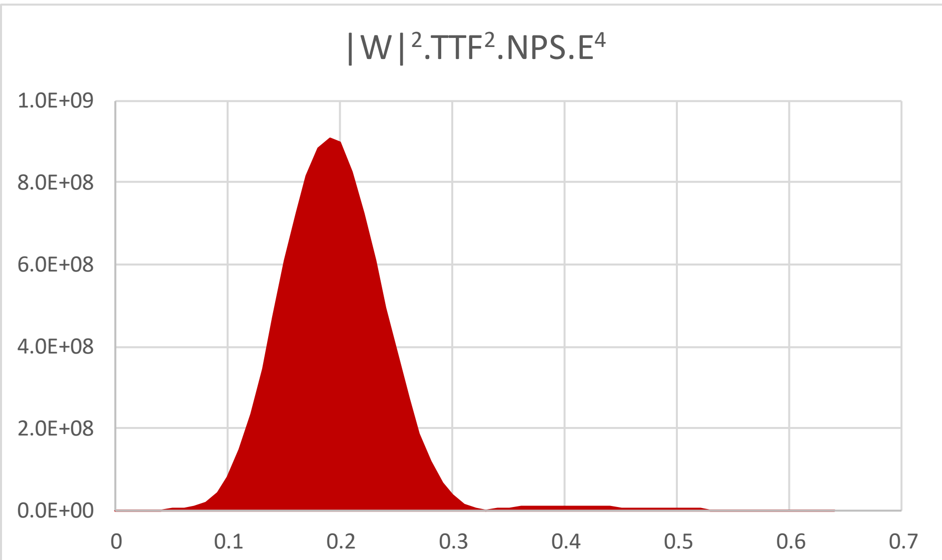




Calculation of d’

$$d'^2 = \frac{\left[\int_0^{f_N} |W(f)|^2 . TTF^2(f) . E^2(f)\, df\right]^2}{\int_0^{f_N} |W(f)|^2 . TTF^2(f) . NPS(f) . E^4(f)\, df}$$





263,126

100,129,054

$$d' = \frac{263{,}126}{\sqrt{100{,}129{,}054}} = 26.3$$

On-going work

- We plan to embed d’ in our CT optimisation work

- We are currently using d’ to compare chest CT protocols across the Trust

Summary

- Written a series of ImageJ plugins to calculate detectability index (d')
  - d' correlates well with human observers [3, 4, 5] and threshold contrast [6, 7]
- Used JetBrains IntelliJ IDEA development environment for the programming [14]
- Used Apache Commons Math library v3.6.1 [15]
- Used Bitbucket for source code management [16]
- Simple validation carried out on each d' component
- d' calculated from images of a Mercury 4.0 phantom[1] to help identify an optimal reconstruction filter for head and neck scans on a CT simulator

Plugin availability

- My source code is on Bitbucket here:
  - https://bitbucket.org/dplatten/imagej-plugins/
  - Download the source code and look in the Javadoc folder for html documentation; there are also comments in the source files

- Compiled jar files are on Bitbucket in the above repository:
  - https://bitbucket.org/dplatten/imagej-plugins/src/e6da6c90b1b13ba1d9139cfbaf744b72e8ae2c89/project-intellij/jars/
  - Download QuantitativeIQ_.jar and put it in the ImageJ plugins folder
  - Put the commons-math3-3.6.1.jar file somewhere where your Java virtual machine can find it, such as:
    - C:\Program Files\Java\jre1.8.0_202\lib\ext
    - It may work if you put it in your ImageJ plugins folder

References

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11. Boone, J.M. et al. (2012). ICRU Report No. 87 Radiation dose and image-quality assessment in computed tomography. Journal of the ICRU, 12(1), https://doi.org/10.1093/jicru/ndt006
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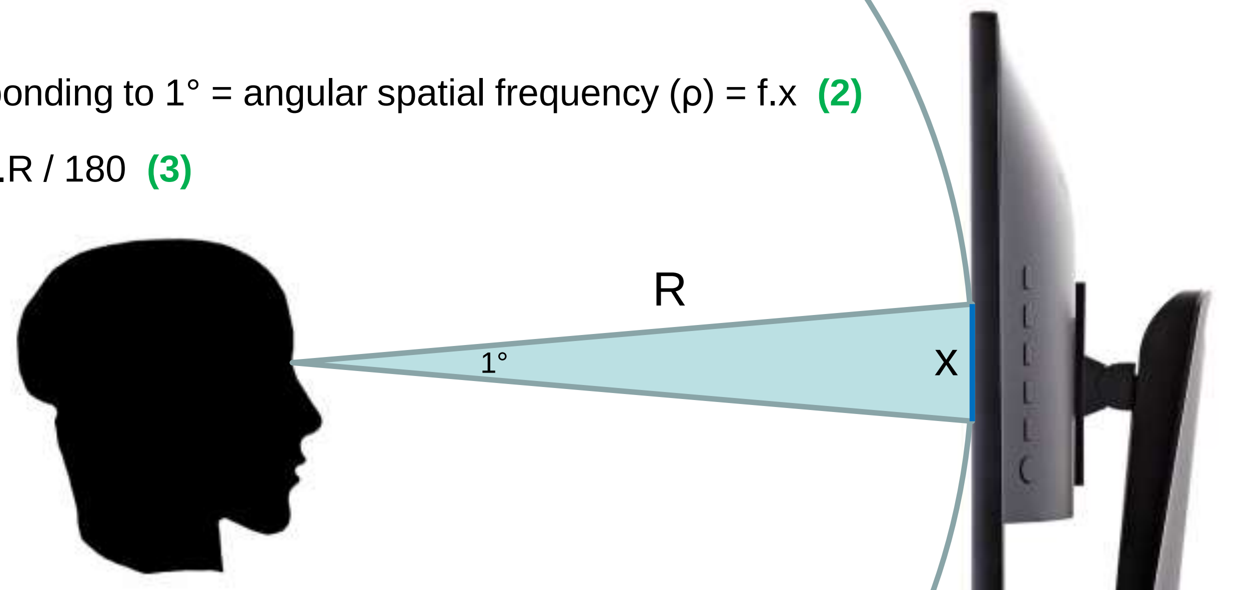
13. Christianson, O. et al. (2015). An Improved Index of Image Quality for Task-based Performance of CT Iterative Reconstruction across Three Commercial Implementations. Radiology, 275(3), pp.725–734, https://doi.org/10.1148/radiol.15132091
14. JetBrains IntelliJ IDEA, http://www.jetbrains.com/idea/
15. Apache Commons Math library v3.6.1, http://commons.apache.org/proper/commons-math/
16. Bitbucket, https://bitbucket.org/

Conversion from image spatial frequency (mm^{-1}) to image angular spatial frequency (deg^{-1})

Circumference C = 2.π.R
Distance x is approximately C / 360 = 2.π.R / 360 = π.R / 180 **(1)**

f = spatial frequency
Line pairs in distance corresponding to 1° = angular spatial frequency (ρ) = f.x **(2)**

Substitute (1) into (2): ρ = f.π.R / 180 **(3)**



The size of the image on the display will not match its reconstructed field of view; this changes the apparent spatial frequencies; correct for this by using the image mag.
Image mag = displayed image size / image reconstruction field of view = D / FOV **(4)**

As mag increases there are fewer line pairs per degree, so need to divide **(3)** by mag:

ρ = f.π.R / 180 / mag = f.π.R.FOV / D.180

where f is image spatial frequency, R is viewing distance, FOV is the image reconstruction field of view and D is the size of the image on the display screen

Thanks for listening

Any questions?