eSAD Workshop – Oxford – 17th Nov-2009
Centre for Study of Ancient Documents

Quality of digitisation

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Guidelines for digitisation

Media Type	Conversion Method	Resolution	Archive File Format	Screen Presentation Format	Print Presentation Format
Black & White Text Document	Flatbed Scanner or Digital Camera	1-bit, 600 dpi	TIFF w/CCITT Fax 4 Compression	GIF, 4-bit, 120 to 200 dpi	Acrobat (PDF), 1-bit, 300 or 600 dpi
Illustrations, Maps, Manuscripts, etc.	Flatbed Scanner or Digital Camera	8-bit grayscale or 24-bit color, 200 to 300 dpi	TIFF	Multiple JPEG, 24-bit, 512x768, 1024x1536, 2048x3072, Quality Level 50	JPEG, 24-bit, 2048x3072, Quality Level 50-100
3-dimensional objects to be represented in two-dimensions	Digital Camera	24-bit color, 200 to 300 dpi	TIFF	Multiple JPEG, 24-bit, 512x768, 1024x1536, 2048x3072, Quality Level 50	JPEG, 24-bit, 2048x3072, Quality Level 50-100

WHY?

http://www.columbia.edu/acis/dl/imagespec.html

Principle

- Archival image records should support all later uses:
  - Reading of text and interpretation
  - Reproduction on display or in print
  - Analysis of material and technique
- Capture as much information as possible from the original document at the time of digitisation:
  - Spatial detail (points, edges, texture)
  - Spectrum of colorants (substrate, inks, paints)
  - Tonal range (lightest to darkest)
- What is not captured cannot easily be regained later!

Object and technology

Consider separately the characteristics of the objects and the device (scanner or camera) for digitisation.

Object	Device
Size and format	Illumination
Fineness of detail	Resolution
Spectrum of colorants	Colour gamut
Density range	Dynamic range

Match the technology to the requirements!

Detail in artefact

What is the finest man-made detail in original surface?

Brush on canvas Pen on paper
Chisel on stone Stylus on clay

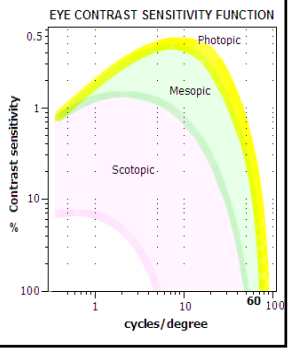
Before opto-mechanical aids, it was limited by:
- Width of tool
- Granularity of substrate
- Manual dexterity
- Visual contrast sensitivity

Important because it sets limit on spatial resolution needed for digitisation.

Punch (1973)

Visual contrast sensitivity

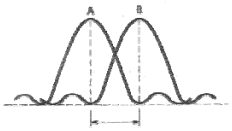
- In bright sunlight, CSF peak ≈ 10 cycles/degree
- At working distance of 30 cm = 20 line pairs/mm
- Requires 40 pixels/mm (1000 dpi) to resolve

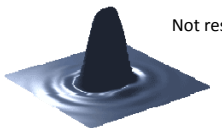


Spatial resolution

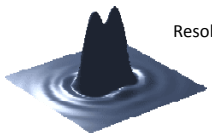
Rayleigh criterion: $R = 1.22N\lambda$

Two points are resolved in optics when the principal diffraction maximum of one coincides with the first minimum of the other.





Not resolved

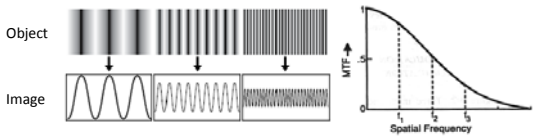


Resolved

Modulation transfer function

Measure of spatial frequency response of imaging system

$$MTF(\xi) = \frac{M_{image}}{M_{object}}(\xi)$$

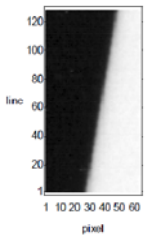


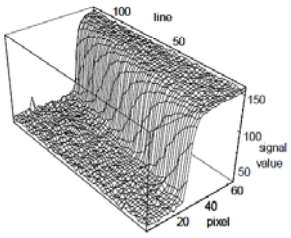
Provides a better indication of spatial resolution than dpi.

Slanted edge processing

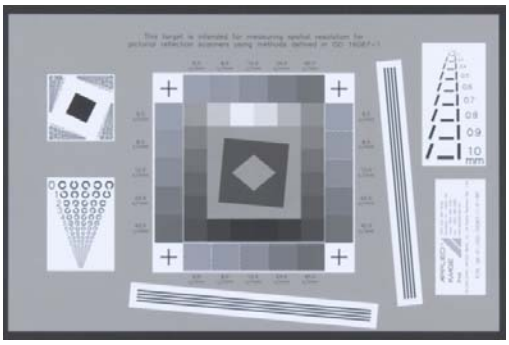
Practical method of determining device's spatial frequency response.

Implemented through standards ISO 12233 and 16067

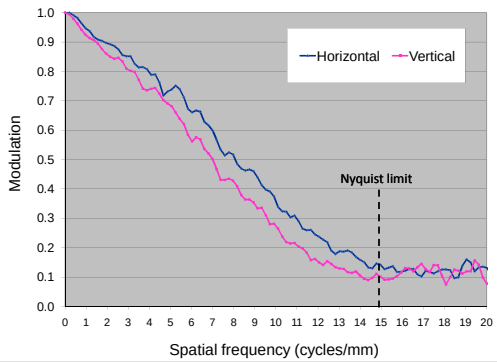




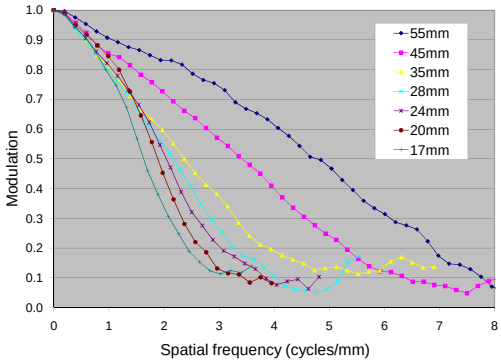
Photographic test target



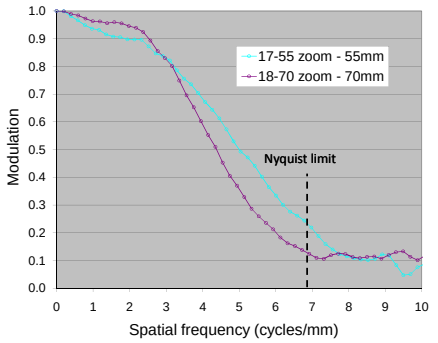
Nikon SFR – 105mm lens

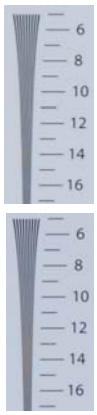


Nikon zoom lens



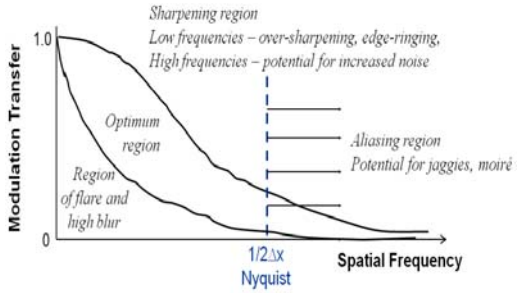
Comparison of zoom lenses





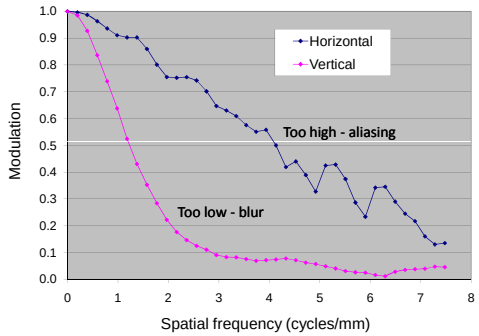
Optimum MTF

Need to achieve the right balance between blur and aliasing.



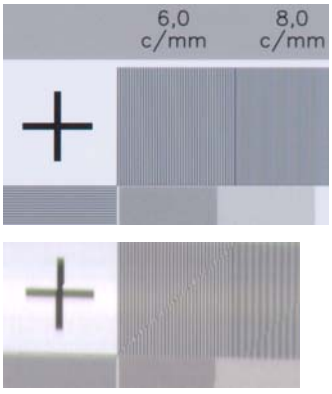
Arius 3D scanner

Arius scanner SFR



Nikon camera with 105mm lens

Arius 3D scanner



Printed facsimile reproduction of illuminated manuscript

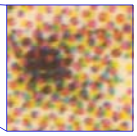
Le Tres Belle Heure de Turin - late 14th Century.

Reproduced by Schwitter (Basel) in 8 inks: CMYK plus blue, orange, brown, gold.

Resolution analysis

- Photographed on a copy-stand with Nikon D200, 105mm lens at 30cm focus distance from surface.
- Image 3900 x 2616 pixels
- Resolution 165 pixels/mm

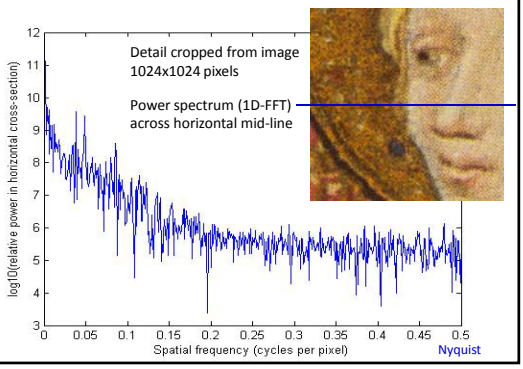
10mm = 1652 pixels



1x1 mm area

Halftone screen
12 lines across
= 300 lines/inch

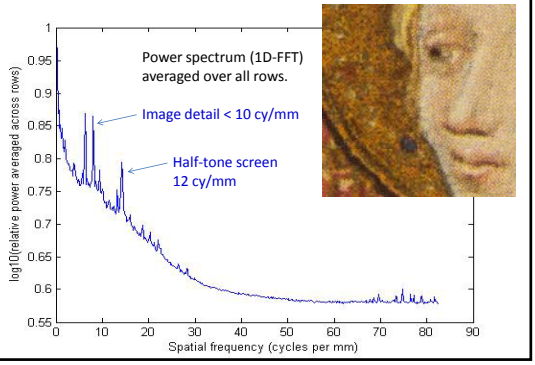
Power spectrum



Detail cropped from image
1024x1024 pixels

Power spectrum (1D-FFT)
across horizontal mid-line

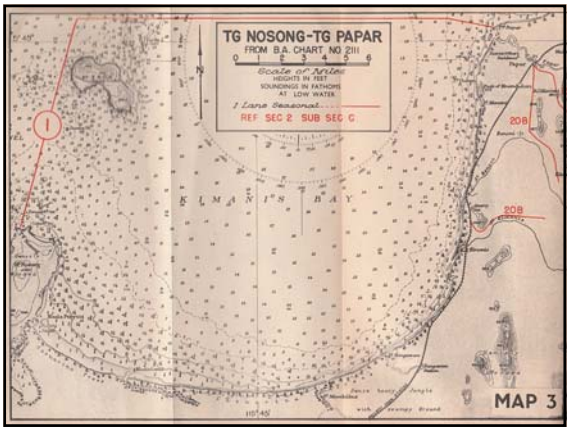
Power spectrum (averaged)



Power spectrum (1D-FFT)
averaged over all rows.

Image detail < 10 cy/mm

Half-tone screen
12 cy/mm



Power spectrum (averaged)

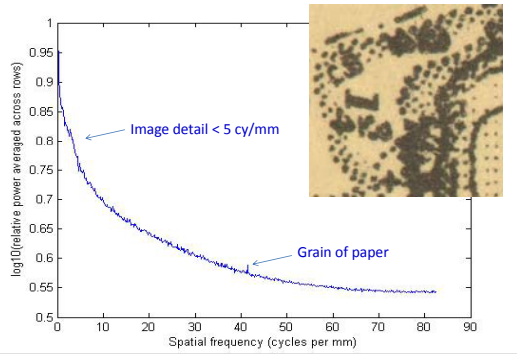
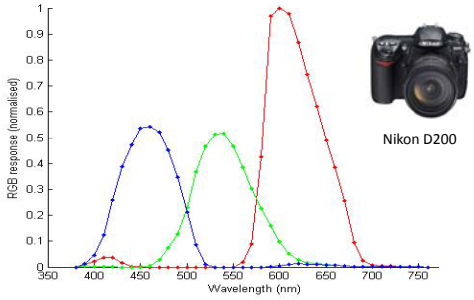


Image detail < 5 cy/mm

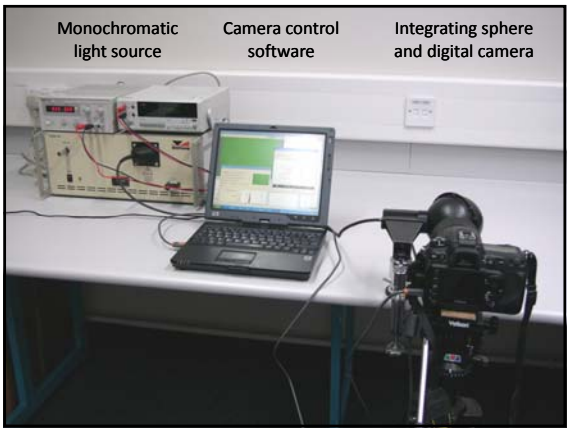
Grain of paper

Camera spectral sensitivity



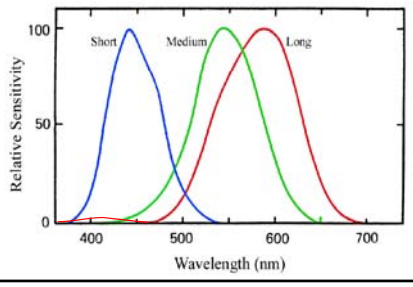
Nikon D200

Nikon D200 digital camera, characterised by monochromatic light source

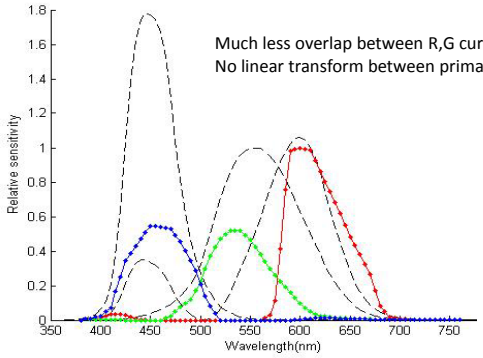


CIE standard observer

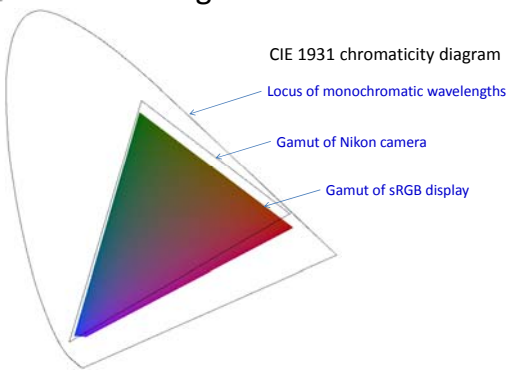
Response depends on spectral sensitivity of L,M,S photoreceptors.
Standard observer is a mean of the colour-normal population.



Camera vs standard observer



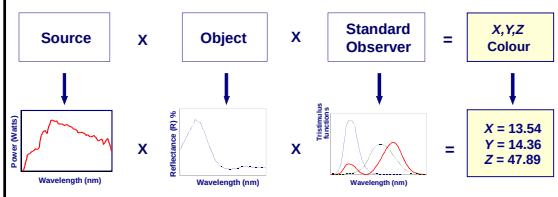
Colour gamut of camera



Computation of *XYZ*

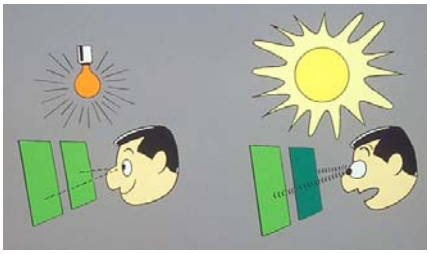
Tristimulus value depends on the illumination, object and observer

$$X = k\sum_{\lambda=380}^{780} S(\lambda)R(\lambda)\bar{x}(\lambda) \qquad Y = k\sum_{\lambda=380}^{780} S(\lambda)R(\lambda)\bar{y}(\lambda) \qquad Z = k\sum_{\lambda=380}^{780} S(\lambda)R(\lambda)\bar{z}(\lambda)$$



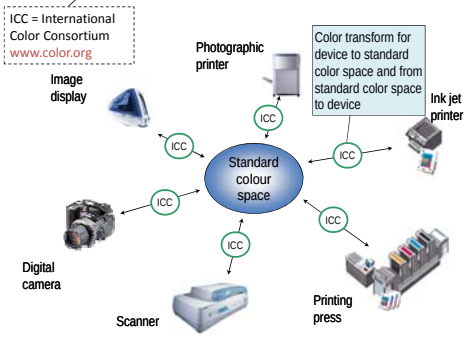
Tristimulus value is a projection of n-dimensional vector space onto a 3-dimensional space, hence many-to-one mapping.

Illuminant metamerism

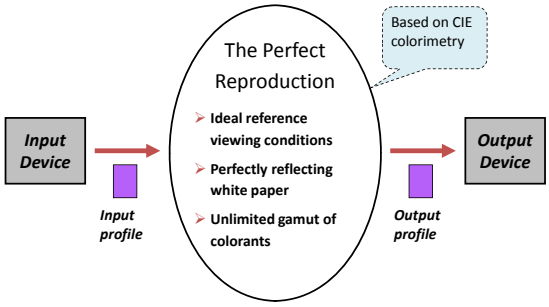


Two colours may appear to match under one source, but appear completely different under another source.

ICC Open Architecture



ICC Profile Connection Space



Characterisation of scanner or camera

Establish relationship: input colour to output signal

Colour → Input device → Signal

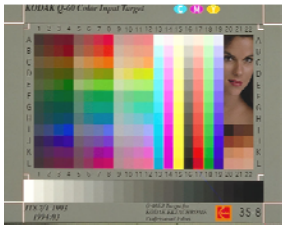
Which signal is generated by a given colour?

Signal = f (Colour)

Colour = f^{-1} (Signal)

Scanner Characterisation

- Use a chart with colour patches of known (measured) spectral reflectance, e.g. ISO 12641
- Digitise the chart and save as image file.
- Average RGB values for each patch.
- Fit polynomials from patch XYZ to RGB.
- Invert polynomials from RGB to XYZ.



Recommendations – spatial

- Analyse the original documents or artefacts to determine the finest spatial detail.
- Choose the best scanner or camera optics to minimise distortion and loss of sharpness.
- Select a sampling resolution (pixels/mm) at least double the highest spatial frequency in the original.
- For a camera, correct the non-uniform distribution of illumination (white card) in the document plane.
- Always store RAW images as the master records – all other formats can be derived.

Recommendations – colour

- Analyse the original documents for dynamic range, and spectral reflectance distribution of colorants.
- Determine the colour gamut of the colorants.
- Ensure that scanner or camera has a colour gamut larger than that of the colorants. If not, consider a multispectral device (more than three channels).
- Characterise the scanner or camera and generate an ICC colour management profile.
- Embed the ICC profile in every image generated.
- Consider HDR imaging (bracketed exposures) if the original has specular reflection (glossy or metallic).