A Simple Approach to Digitising a Photographic Collection

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Abstract

This paper reviews the processes involved in the digitisation, display and storage of medium size collections of photographs using simple and inexpensive, commercially available equipment. It is also aimed to provide a guideline for evaluating the performance of such imaging devices on aspects of image quality. A collection of slides, representing first-generation analogue reproductions of a photographic collection from the nineteenth century, is treated as a case study. Constraints on the final image quality and the implications on the digital archive are discussed along with a presentation of device characterisation and calibration procedures. Summary results from objective measurements carried out to assess the systems are presented. The issues of file-format, physical storage and data migration are also addressed.

Introduction

The digitisation of many art collections has taken place in the last ten years[1,2]. In this paper we discuss the processes involved in the creation of a digital collection of images using mid-range commercially available equipment.

A photographic collection of seven hundred 35mm transparencies is treated as a case study. The collection represents first-generation analogue copies of photographs belonging originally to W.H.F. Talbot. Today the originals are part of the photographic archive of the Royal Photographic Society (RPS) in Bath, UK. The Talbot collection has been rarely viewed and cannot be exhibited due the detrimental effects of handling and light exposure on these early photographs. This encouraged the RPS to produce five years ago copies on 35mm Kodak Ektachrome transparency film. Analogue copies however also require appropriate storage for maximum life expectancy and offer few advantages in accessing the collection compared to digital reproductions.

The description of the imaging stages involved in the development of a digital collection of photographs is illustrated in Figure 1. This is a complex operation, involving many decisions concerning the way the original image is digitally acquired, post processed, saved in an appropriate colour space, format and medium and finally delivered to the user. A priori, there is no ‘correct’ method for digitising photographs. Photographic images contain a high density of information and require very high quality digitising procedures to retain all their characteristics. The choice of equipment and methods determines the quality of the reproduction and depends on the use and purpose of the digital archive as well as budget constrains. Thus, before starting the digitisation process, it is essential to define the purpose of digitisation and the use of the acquired images. Quality criteria may then be established[3,4].

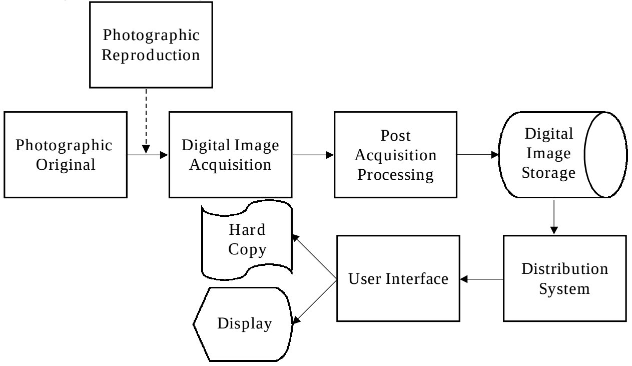


Figure 1: The steps involved in the development of a collection of digital images.

For the `Talbot project’ the aim was to provide wide accessibility to a digital version of the photographic collection, that would be rendered in such a way as to approach the present appearance of the archived photographs. The digitisation process involved the production of high spatial resolution digital image files from the slide duplicates. The future use of a digital archive cannot be predetermined and therefore a digital archive should not in principle be optimised for a specific output[3]. Limitations in the colour resolution (bit-depth) of the acquisition device and the need for immediate output via common commercial applications forced us to select a primary output device, the CRT display. The spatial resolution of the digital images allows reproductions on film and prints of up to the original size (below A4 size).

In this paper we focus on the image acquisition and post-acquisition processes and the storage of the images. The first generation analogue reproductions are treated as ‘the originals’, therefore any quality associations are made between the slides and the digital reproductions. Aspects of image quality are investigated by implementing objective measurements, known to be consistent with the HVS. Information on the distribution system and the user interface can be found in reference[5].

Digital Image Acquisition

Successful digitisation relys principally on the image acquisition system. After a review of previous projects and an extended market survey on digital image acquisition devices, it was decided that the Talbot collection would be digitised using the Nikon LS-1000 35mm slide scanner.

The Nikon LS-1000 operates in the following fashion: Red, green and blue light is flashed, one at a time, from a LED array. A transmitted spectrum, for each flash, results when the incident light is selectively absorbed as it passes through the film layers and the optical system of the device. A linear monochrome CCD array of 2592 pixels scans the image plane sequentially. The resulting CCD voltages are scaled and converted to 12-bit per channel digital values. The 12-bit digital signal is optimised down-sampled to 8 bits for output. The spectral responses of the red, green and blue channels are determined by the spectral distribution of the LEDs, the spectral transmittance of the optical lenses, the sensitivity of the CCD detector and the spectral transmittance of the specific film.

The device scans transparent originals of up to 34.3 mm by 36.5 mm. Its spatial resolution allows maximum image dimensions of 2592 by 3888 square pixels, of 9.4 μm x 9.4 μm size, resulting in 28.8 MB colour digital image files. The pixel dimensions were confirmed experimentally by scanning targets with known physical size[6]. The maximum spatial frequency sampled faithfully by the device is $1/(2\delta x)$ (δx being the sampling interval) or 53.2 cycles per mm. This does not cover the entire bandwidth of photographic films, such as the Ektachrome 100 ISO used in the project, having a theoretical cut-off frequency of 100 cycles per mm (determined by extrapolating the spatial frequency response curves provided by Kodak[7]). Beyond the Nyquist limit, aliasing occurs. It is prevented in modern scanners by the use of anti-aliasing filters[8].

The voltage output of the CCD of the Nikon LS-1000 is initially quantized to 12 bits per colour component, providing 4096 code levels and theoretically covering a density range of 3.6 (approximately the density range of slide films). The electronic noise and quantization noise as well as flare due to light scattering through the lenses reduce significantly the dynamic range of the scanner to approximately 2.7 to 3.0 density units. The tonal range of the original is therefore compressed and optimised by the device or/and according to the scanner operator's settings. In the digitisation of original artwork the loss in the dynamic range is a serious disadvantage and unless the data contain the full dynamic range of the original, the digital archive is considered to be inferior to the stored transparencies.

Tone Reproduction

The tonal characteristics of the scanner are most commonly described by the relationship between input transmittance and the generated pixel values. Although most such systems respond linearly to intensity and therefore to transmittance, the scanner transfer function can be represented with power functions (see Equation 1), since there is often (as in the case of the Nikon LS-1000) a non-linear mapping of the output signal.

$$d = k_o + t^{\gamma} \qquad (1)$$

d is the generated normalised pixel value, k_o is the system offset and t is the film transmittance. The exponent γ_s describes the non-linearity in the contrast of the acquired image and varies primarily according to the selected *gamma setting*. An offset in the positive direction can be caused either by an electronic shift or by stray light in the system. While the electronic offset can be set equal to zero and offset from uniform stray light can be adjusted out electronically, signals from flare light (i.e. the stray light coming though the lens) and stray light from the illumination system are often image dependent[8].

The scanner transfer function can be determined by averaging the response of the system to uniform transmittance steps of a conventional greyscale, or to a smoothly varying transmittance grey wedge. Strictly, the resulting curve represents an average response to the specific input target and target positioning[8]. Figure 2 illustrates in log-log space the RGB responses of the Nikon LS-1000 to the Q-60 target on Kodak Ektachrome colour transparency film. The test target includes a 24-step greyscale, covering the entire dynamic range of the material. The result shows that only a part of the curves is a straight line, corresponding to a range of input densities between 0.3 and 2.2. Only within this density range the power relationship in Equation 1 is valid.

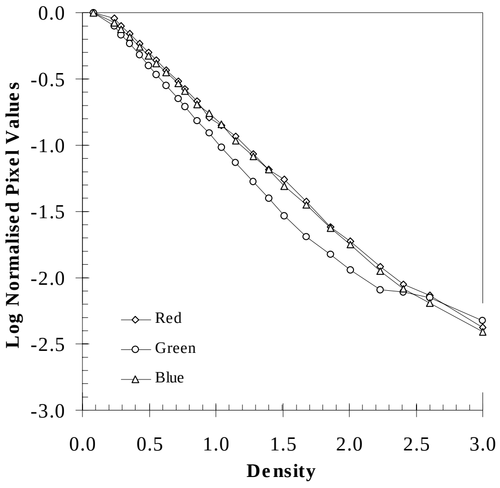


Figure 2: Scanner RGB responses to the Q-60E3 target.

Sharpness

The sharpness of the Nikon LS-1000 was assessed by measuring the MTF. The MTF of such systems is the product of the MTFs of the detector, optics, and electro-mechanical components. The basic detector MTF, $M_d(\omega)$, is defined by the size of the square aperture of the individual pixels:

$$M_d(\omega) = \frac{\sin(\pi\omega x)}{\pi\omega x} \tag{2}$$

where x is the linear dimension of the imaging aperture and ω the spatial frequency. Equation 2 defines the maximum MTF of the detector, obtained when the centre of the pixel coincides with the optimum recording of the maximum of a signal. There are further characteristics other than the geometric shape of the detector that affect its frequency response, such as misdiffusion, charge transfer inefficiency, time-delay and integration errors[9].

The optical system of the scanner consists of several lenses with varying focal length, varying indices of refraction and elements to minimise lens aberrations. For modelling purposes the lens system can be treated as a single diffraction limited lens[9]. Further degradation in the optics MTF is caused by the anti-aliasing filter, which can be modeled by the birefringent technique[10].

The MTF of the electro-mechanical components of the device is basically governed by the stepper-driven mechanism. This introduces a certain level of vibration while imaging. The MTF of such a system has not been considered. Two general models for MTF degradation due to motion can be combined as an approximation. The first is the linear motion MTF, affecting the frequency response of the system in the direction of the motion[9]. The second, representing often degradation due to random jitter, is the random motion MTF, described by a Gaussian having a standard deviation equal to the rms random displacement[11].

It is widely known that in imaging systems the measured MTF depends critically on the method of measurement due to the non-linearities the systems introduce. The MTF of the Nikon LS-1000 was determined using three different techniques, which yield different results[12]. Figure 3 presents MTFs for the fast and slow scanning directions of the scanner, evaluated using the ISO 12233 Slanted Edge SRF plug-in[13] and two test targets with different contrast. The curves represent the monochrome frequency responses of the centre of the scanning frame.

When an edge exposure is reproduced on film, scanned and processed using the plug-in, the resulting SFR is the product of the frequency content of the test-target and the MTF of the scanner. The MTF curves presented in Figure 3 were evaluated by scanning custom-made test-targets. The targets were images of very high quality laser printed step-edges, printed as binary files. The prints were recorded on fine grain B&W film at different exposures and at various angles from the vertical[12]. The frequency content of the edge-targets was determined using the traditional edge technique[14]. It was removed from the measured SFR to obtain the MTF of the scanner.

In Figure 3, it is shown that the MTF is very similar for both scanning directions, with the slow scan having a slightly lower response at frequencies beyond 15 cycles/mm. Since the imaging aperture of such devices is most commonly square[9,15] an isotropic scanner response at 90° orientation is expected. The use of edge-targets with little difference in contrast gave very similar results.

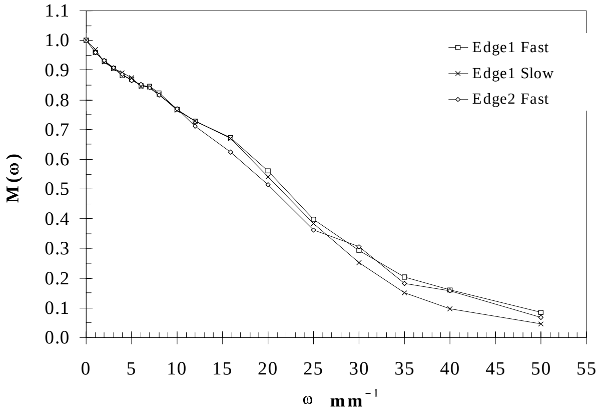


Figure 3: Scanner MTF for the fast and slow scans.

Spatial Uniformity

Many parameters introduce non-uniformities within the scanning area, such as LED and electricity inconsistencies, CCD and stepper-driven stage speed variations and others. By examining the statistical distribution of the scanner responses to a fixed density, the magnitude and position of the uniformity error can be identified. The problem however with this type of analysis is generating uniform targets, especially for the assessment of film scanners[6,16].

The spatial uniformity of the scanner was evaluated in density units, by employing a uniformity target created by Kodak and used internally to characterise capturing devices[16]. The target was kindly lent for this project by the Eastman Kodak research laboratories in Rochester, NY. It contains forty individual squares (8 x 5 grid) indicating characterised areas, where the scanner's uniformity is assessed. Although the scanner's error is known to vary with the level of scanner responses, only targets with average density around 1.70 were available. The monochrome uniformity profile of the scanner - around zero density - is illustrated in Figure 4. Higher scanner responses are indicated in the middle of the frame and lower responses mostly on the top and then on the bottom of the scan. The density fluctuations range between +0.01 and -0.03 density units from a zero mean density. Colour scans presented higher non-uniformity, mostly due to the inconsistencies of the red channel, which exhibited density fluctuations between +0.02 and –0.04 units. The magnitude of the error was smaller in the green and blue channels.

A correction factor for each pixel location can be built by applying 2-D interpolation to the measured points, to compensate for the device’s non-uniformity. In the Talbot project this task was avoided since it can produce quality problems of a different nature, such as contouring artefacts, due to quantization errors in the 24-bit scanner output space. Additionally, information on the error at different levels of scanner's response would be necessary to build a complete correction model dealing with real and tonally complex images.

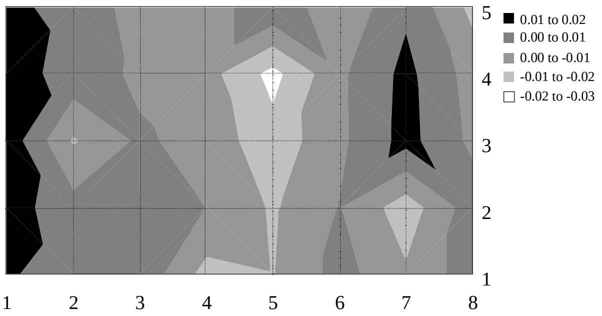


Figure 4. Monochrome uniformity profile of the scanner.

Colour Characterisation

Device independent colour requires a colorimetric scanner. The Nikon LS-1000, as most commercial scanners, is not colorimetric. Various workers have proposed different methods to produce colorimetric values from non-colorimetric scanners over the last decade[17,18,19,20]. The colorimetric characterisation of the Nikon LS-1000 was achieved using a polynomial regression to derive a correction matrix for colour transformation[17]. The success of this method for device characterisation depends on the space chosen for the transformation, the number and position of colour used as training samples, the choice of the specific polynomials and their degree. The method consists of two steps: the grey-balance of the red, green and blue signals for the neutral patches of the calibration target and the derivation of a 3 x m (where m is the number of polynomial terms) colour correction matrix. Polynomial regression is applied to selected samples with known colour specifications in both source (CIEXYZ was chosen here) and destination (grey-balanced RGB) colour systems.

The polynomial regression method for device characterisation is constrained to a single set of dyes, illuminant and observer. Since the RPS collection of slides was on Ektachrome material, the Kodak Q-60 test target on Ektachrome transparency film was selected to best characterise the scanner for this application. The target fulfils the requirements of a test object for an input colour scanner[22], providing uniform mapping in the CIELAB colour space. All the 264 patches of the Q-60 were used as training samples. The target illuminant and observer were set the CIE illuminant D_{65} and the CIE 1931 2° Standard Colorimetric Observer respectively.

The performance of 6 colour correction matrices, with m ranging from 6 to 31, was assessed in ΔE^*_{ab} units. Results are presented in Table 1 ($\Delta E^*_{ab} < 2.5$ was considered as the limit of perceptibility for displayed complex scenes[23]). Figure 5 illustrates the distribution of in ΔE^*_{ab} for the three most successful matrices. Overall, the results are not satisfying, until the 3 x 31 matrix where the average ΔE^*_{ab} is 2.12 and 77% of the samples have ΔE^*_{ab} below 2.5. Still maximum ΔE^*_{ab} are very high.

Table. 1: Average and maximum ΔE^*_{ab} for 6 correction matrices

m	Average ΔE^*_{ab}	Max. ΔE^*_{ab}	ΔE^*_{ab} <2.5 (%)
31	2.12	14.69	76.8
19	2.84	21.14	62.6
13	4.49	43.45	43.6
10	4.80	51.13	40.5
6	7.37	69.73	35.2

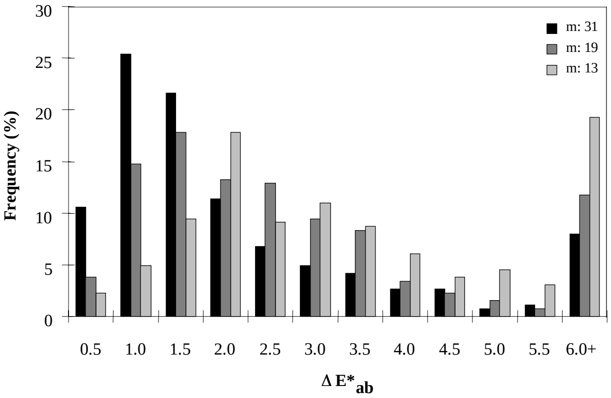


Figure 5: Distribution of ΔE^*_{ab} between original and estimated CIELAB values for 3 correction matrices.

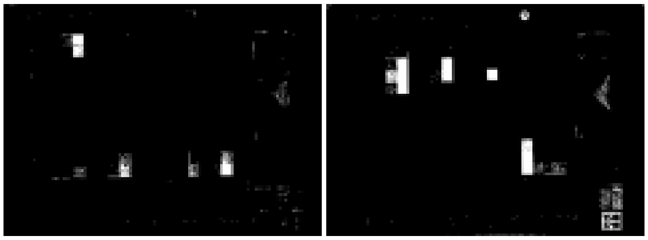
A comparison between the original and those estimated with the 3 x 31 matrix CIE a^* and b^* chromaticities, for all the samples of the Q-60, indicated that the larger mismatches occurred in the yellow-green and blue-red either saturated or very dark samples. Less distinct mismatches were reasonably random. The average and maximum ΔL^*, ΔC^*_{ab} *and* ΔH^*_{ab} were found 0.28, 1.46 and 1.25 and 2.18, 14.21 and 10.62 respectively (i.e. the colorimetric differences were mostly due to chroma and then to hue errors). An additional limitation of the transformation was the loss of grey balance. Inaccurate estimates were made for the darker neutral patches of the target, where significant chroma and hue errors resulted to ΔE^*_{ab} values up to 8.15. The RPS slides were finally converted to colorimetric digital files using the 3 x 31 colour correction matrix. A problem thought with high order transformation equations is that they can lead to unsatisfying performance in practice. This is a result of fitting random error in addition to the desired systematic trends and noise amplification[17].

Image Encoding for Display Output

Direct access to the digital images via most commercially available systems was achieved by converting the calibrated image data from the CIEXYZ D_{65} system to the Standard RGB colour space[24]. In the sRGB encoding process, a number of original tristimulus values are clipped to fit the gamut of modern CRTs. The percentage and position of the clipped colours are shown for the Q-60E3 target in Figure 6; colours out of the sRGB gamut are indicated in white.

Q-60E3

Red Channel - 5.0%



Green Channel - 1.4%

Blue Channel- 2.5%

Figure 6: Colours of the Q-60E3 out of the sRGB gamut.

The loss in the available gamut by encoding in sRGB space is a drawback in the uses of the digital images. For instance, hard copy media, which have very different colour gamuts than those of modern CRTs, can produced some colours which are lost during the encoding processes. Furthermore, future display devices may allow better image rendering and thus the data will be of a limited value.

For communicating the images in other than sRGB compatible media, an sRGB ICC profile[25] was provided together with the digital images. A pre-requirement for correct colour imaging is that the profile of the output device, including the viewing conditions, must also be on hand. The ICC architecture, in many cases has helped significantly the communication of colour in various media; nevertheless, it has their own limitations. These lay mainly in the way the PCS (profile colour space) defines various aspects of the reference space[26]. Additionally, the future of ICC profiles is not known. Currently various users refuse to incorporate them in their files.

Storage and Data Migration

International storage standards were used to provide easy access while enabling the digital files and storage media to be successfully migrated to future media and formats. The processed images were saved as TIFF files and were stored on an ISO 9660[27] format writable compact disks (CD-Rs). The TIFF is thoroughly documented and the source code is available. Easy access and retrieval makes TIFF the most advisable image file format for image archiving purposes[28]. The ISO CD-ROM recording also allows access to the data from all current platforms and operating systems.

Longevity in all storage media depends on the stability of the medium, the storage conditions and the handling[29]. CD-ROM degradation is caused by oxidation and structural changes and therefore storage temperature and humidity are determinants of the useful lifetime of the disks. Optical media manufacturers, claim estimated physical lifetime for CD-ROMs of approximately 100 years, but without handling, and give a guarantee of 25 to 30 years[30].

Unfortunately, it is impossible to rely on the hardware and software (H/S) used to read, write and store the digital images being available in the future. Therefore, preservation of information on optical disks means transferring from obsolete to newer systems, i.e. data migration. There is no degradation in the digital migration process. Provided that migration periods are well defined and refreshing of information is performed on time the digital archive should have long life access.

The support of the TIFF is the major concern governing the migration periods of the digital archive. The first version of the TIFF specifications was published in 1986 and since the structure of TIFF has been expanded around a basic frame, which makes the older versions backwards compatible. The current TIFF 6 revision was released in 1992[31]. Obsolescence of the H/S used to read the optical disk is another issue. Associated H/S includes the CD-ROM reader, the software driving the reader (driver), the host computer and its operating system. Hardware nowadays becomes obsolete in relatively short periods; a new generation is expected approximately every two years. Generally, a new generation of hardware is backwards compatible for two generations[28]. Driving software usually changes with or within the lifetime of the device (hardware) to be compatible with newer operating systems, providing new features to the user. A given device can be operated by four successive generations of drivers. Operating systems are renewed every one to three years, but usually run drivers written for the previous two versions. In total, although optical disks have a relatively long physical lifetime, the estimated time of obsolescence of a particular recording due to H/S configuration is estimated between 5 to 8 years[28,32].

Eventually, the physical media supporting the digital image archive will become obsolete. The Digital Versatile Disk (DVD), of same physical size as the CD-ROM (120mm) but with increased data capacity, seem today the obvious successor. A considerable advantage for the useful lifetime of the CD-ROM archive as well as for the migration of the data from this media is that several manufacturers currently distribute platforms with DVD-CD-ROM drives. DVD media are being developing assuming the heritance of existing software resources and will continue to maintain compatibility in the future[33]. Otherwise, storing yearly back-up copies on magnetic tapes is an advisable practice. Magnetic tapes are cheap, have large capacity but short physical lifetime.

Conclusions

In this case study, the objective for digitisation was to provide wide accessibility to a collection which otherwise was closed to viewing, while allowing a satisfactory quality, so that ideally original images would not need to be accessed and scanning would not be necessary in the near future. Digitisation was performed using a mid-range commercially available scanner. The characterisation of the device showed that the system imposes serious quality constraints on the reproduction. In terms of tone, the dynamic range of the scanner is not capable of covering the entire dynamic range of the original material. Additionally, the 24-bit scanner's output space limits the precision of post acquisition processes, necessary for calibrating the digital images. Currently many inexpensive scanners now provide 36-bit output data. In sharpness assessments, measurements of the scanner monochrome MTF indicated a considerable loss in modulation, even at low spatial frequencies. The MTF degradation could be partially compensated with the use of digital filters providing boost[9]. This is a twofold solution and if it is performed it should be done with caution, since excessive boost may cause ringing at sharp edges. The colorimetry of the device was characterised using polynomial regression, which gave satisfactory results only when a large number of polynomial terms were employed. More specifically, from six correction matrices employed, only the 3x31 matrix produced average ΔE^*_{ab} within the limit of perceptibility for complex scenes, displayed on CRTs. The choice of image encoding to the sRGB space for display output was a trade-off between direct accessibility from many commercial systems and significant losses in the available colour gamut.

Colorimetric images were stored using file format and media compatible with the majority of current H/S configurations. A requirement for securing the longevity of the digital archive is the migration of the data from the current format and medium to newer systems. The migration process is a demanding operation, involving the follow-up of the technologies and has considerable costs. Whether the produced image data is worth migrating will depend on the current use of the digital archive (i.e. to what extend it is used and how well it satisfies the needs of the users), as well as on future improvement of the imaging systems (i.e. available data might be of an insufficient quality compared to newer systems and standards).

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Biography

Sophie Triantaphillidou received a first class honours BSc degree in Photographic and Electronic Imaging Sciences from the University of Westminster in 1995. She is currently a research fellow in the Imaging Technology Research Group at the same University, having recently completed a PhD project on the digitisation and display of photographic collections. Research interests include issues of image quality of analogue and digital systems.