Ecole du Louvre
ICHIM
Paris 03
www.ichim.org

Les institutions culturelles et le numérique
Cultural institutions and digital technology

École du Louvre
8 - 12 septembre 2003

DIRECT DIGITISATION OF DECORATED ARCHITECTURAL SURFACES

Keith Findlater, Lindsay MacDonald, Alfredo Giani - University of Derby, Kingsway House East, Kingsway, Derby, UK

Barbara Schick - Bayerisches Landesamt für Denkmalpflege, Munich, Germany

Nick Beckett - Metric Survey Team, English Heritage, York, UK

« Acte publié avec le soutien de la Mission de la Recherche et de la Technologie du Ministère de la Culture et de la Communication »

Abstract

The European project IST-2000-28008 'Veridical Imaging of Transmissive and Reflective Artefacts' (VITRA) commenced in March 2002. It aims to facilitate the capture of high-resolution digital images of decorated surfaces in historical buildings. The principal objective is to design and develop a robotic carrier for a digital camera for remote acquisition of colorimetric images. Image processing algorithms are being developed for registration and correction of multiple adjacent images, channelling the stitched results to an image database for storage/retrieval adapted to the needs of users. Techniques will be explored for the interactive three-dimensional visualisation of the decorative images in augmented-reality settings.

The consortium includes two user organisations, English Heritage (UK) and the Bayerisches Landesamt für Denkmalpflege (Germany), who are both extensively involved to establish imaging requirements for decorative surfaces in heritage building, and to demonstrate system operation at several sites of historical importance in the two countries. In the UK, St. Mary's Church at Studley Royal, a Victorian church near Fountains Abbey in North Yorkshire and a UNESCO World Heritage Site, has been chosen for its wide variety of media (exquisite stained glass, wall paintings and encaustic tile pavement), while at Peterborough Cathedral the painted nave ceiling will be surveyed and recorded. In Bavaria, Walhalla ("home of the Gods") has been chosen for conservation of its unique coffered metal ceiling, while Regensburg Cathedral has been selected for analysis of weathering damage to its exterior stonework and its famous stained glass windows.

A key aspect of the project will be the development of a suitable robotic carrier to lift a digital camera (actually a digital back on a medium-format studio camera) with illumination to an operating height of up to 15 metres above floor level. This will replace conventional photographic platforms such as scaffolding and 'cherry pickers', and is very attractive for survey purposes because it will be transportable and operable by a two-man team, and quick to put up and take down. It will be possible to position the camera repeatedly to an accuracy of 1 mm, using laser positioning devices, with three degrees of freedom on top of the robotic mast, including 360° horizontal rotational movements for the capture of full panoramic images. The German partner Jenoptik is adapting a CCD array of size 4Kx4K pixels for use with

Balcar flash illumination in a single-shot image capture mode, fixed to a new Rollei 6008AF auto-focus camera body with Schneider and Carl Zeiss lenses.

This paper will describe the VITRA robot in production including the camera and lighting platform together with the proposed lighting geometries. It will also refer to the issues of planning on-site photography, positioning of camera and illumination relative to the surface, control of the robotic apparatus, use of calibration charts, processing and database storage of images, and evaluation of the results. The image acquisition software chain and image processing applications including stitching and mosaicing techniques will be described in relation to the image capture of decorated architectural surfaces including stained glass windows.

1. INTRODUCTION

The European project IST-2000-28008 'Veridical Imaging of Transmissive and Reflective Artefacts' (VITRA) commenced in March 2002. It aims to facilitate the capture of high-resolution digital images of decorated surfaces in historical buildings. The principal objective is to design and develop a robotic carrier for a digital camera for remote acquisition of colorimetric images. Image processing algorithms are being developed for registration and correction of multiple adjacent images, channelling the stitched results to an image database for storage/retrieval adapted to the needs of users. Techniques will be explored for the interactive 3-D visualisation of the decorative images in augmented-reality settings.

The consortium includes two user organisations, English Heritage (UK) and the Bayerisches Landesamt für Denkmalpflege (Germany), who are both extensively involved to establish imaging requirements for decorative surfaces in heritage building, and to demonstrate system operation at several sites of historical importance in the two countries. In the UK, St. Mary's Church at Studley Royal, a Victorian church near Fountains Abbey in North Yorkshire and a UNESCO World Heritage Site, has been chosen for its wide variety of media (exquisite stained glass, wall paintings and encaustic tile pavement), while at Peterborough Cathedral the painted nave ceiling will be surveyed and recorded. In Bavaria, Walhalla ("home of the Gods") has been chosen for conservation of its unique coffered metal ceiling, while Regensburg Cathedral has been selected for analysis of weathering damage to its exterior stonework and its famous stained glass windows.

A key aspect of the project will be the development of a suitable robotic carrier to lift a digital camera (actually a digital back on a medium-format studio camera) with illumination to an operating height of up to 15 metres above floor level. This will replace conventional photographic platforms such as scaffolding and 'cherry pickers', and is very attractive for survey purposes because it will be transportable and operable by a two-man team, and quick to put up and take down. It will be possible to position the camera repeatably to an accuracy of 1 mm, using laser positioning devices, with three degrees of freedom on top of the robotic mast, including 360° horizontal rotational movements for the capture of full panoramic images. The German partner Jenoptik is adapting a CCD array of size 4Kx4K pixels for use with Balcar flash illumination in a single-shot image capture mode, fixed to a new Rollei 6008AF auto-focus camera body with Schneider lenses.

This paper will outline the issues of planning on-site photography including a range of photographic techniques and equipment used for imaging architectural surfaces for record and conservation applications. Also the basic positioning of camera and illumination relative to the surface, use of calibration charts, processing and database storage of images, and evaluation of the results. The photographer has use of all the technical aids at his disposal to produce images suited to the needs of users, while having some creative latitude to interpret the scene by selection of composition, depth of field, tonal rendering, etc. With delicate surfaces such as wall-paintings and stained glass windows, particular care must be taken not to cause damage, following good professional practice in conservation photography.

The overall flow of images can be represented as in Figure 1. The camera produces a raw image, which is then transformed by image processing procedures to 'normalise' it in terms of geometry, uniformity, tone, colour, and sharpness. This image is stored in the database, with the addition of appropriate metadata (place and time of capture, photographic parameters, etc.). Subsequently the image may be accessed by a user, such as a surveyor or conservator, via Adobe Photoshop software on a desktop computer. Additional plug-in software modules will add functionality to assist the user in image analysis and interpretation. This paper will also give an overview of the image processing software being developed in the VITRA project including the transformation from raw to corrected image, and the functional modules for user image analysis.

2. PLANNING SITE PHOTOGRAPHY OF ARCHITECTURAL SITES

2.1 Overview

Photography is the primary medium for documenting a historical site at a defined time and for preserving this information for the next generation. This section will describe the different types of photography and digital imaging used for historical buildings. It is important to consider that the images produced are often made for the national archive when dealing with cultural objects, therefore the images should be always taken to the highest possible quality. Producing and archiving this information is vital for future use, for restorers, historians, architects and the public. Sometimes the detailed early photographs from the 19th century may be the only information we can rely on. For conservation records, a good image needs to be a true representation that shows the required information.

2.2 Preparation

The professional photography of decorated architectural surfaces is normally client driven so a request is initially made specifying imaging requirements and includes relevant site information. The photographer assesses site conditions such as aspect, access and lighting, and evaluates the nature of the subject and its surroundings. Clients such as conservators, archaeologists and architects meet the photographer for a preliminary site visit to discuss requirements and the possibilities of image capture. The input of the photographer usually influences the style and technique of the required imaging. Bringing together the expertise of the different disciplines guarantees a professional result.

Physical constraints can be assessed including access, power supply and scaffolding requirements. Such forward planning and preparation supports economic working. The majority of historic monuments have previous documents, so that this together with any other client information will help the photographer to have a clear idea of the project. The architectural drawings are also used to estimate and plan the imaging program.

2.3 Photographic techniques

Photographic techniques are chosen depending on the equipment available and budget to meet the user requirements. Records of scale and resolution settings are made for a range of diverse images produced by a wide range of photographic equipment available.

Record Photography

Record photography is the main style of image capture for historic sites and is distinguished by being a form of scaled image. It can comprise three styles including metric, rectified and conservation photography. Conservation photography doesn't refer to any specific photographic techniques: it specifies the purpose of the captured images that are captured using established methods of record photography.

Pictorial photography

Pictorial photography includes documentary and panoramic photography. Pictorial photography gives wider extra information of the surrounding and the spirit of the object of art. That helps orientation and attracts people to site visits, for example, by publishing the film images on the internet.

Documentary photography

Architectural heritage such as listed historical buildings is also photographed for archival documentary purposes. Such images depict the cultural history of architecture and create an important visual record of how buildings and sites change throughout time. The fabric of these buildings can vary enormously, ranging from domestic dwellings to industrial sites, municipal buildings to ecclesiastical architecture, factories, mills, mines, pubs, prisons, sports stadium, country houses and gardens and more. This is an important form of documentary photography especially when planning consent is given to redevelop or demolish buildings. In this case the buildings are recorded before alteration. This has been particularly important in recording industries such as the English coal mines which were quickly closed down in the early 1990s.

Panoramic Photography

Digital images have many image processing applications to enhance captured scenes. Panoramas can be made by taking an incremental series of photographs to make a 360º rotation. The number of increments depends on the angle of view of the lens and the overlap required between each image. These form cylindrical and cubic image spaces depending on the software used. The panoramas can be integrated into a site plan where an augmented reality walkthrough can be made. This is an image capture process that enables interactive viewing from a computer monitor and is a documentary form of heritage imaging. This offers the scope for atmospheric and creative photography.

Metric

Stereoscopic images are adapted for the application of photogrammetry. The image format is 60mm x 60mm or larger. Glass plates assure that the film is levelled. A fixed focus lens with minimal distortion is calibrated at a precise focal length within 0.01mm. The images taken under even diffuse illumination creates together with survey dates and exact architectural plan.

The accuracy is at a standard 0.18mm line width

For 1:50 output scale, 9mm in reality

For 1:20 output scale, 4mm in reality

For 1:10 output scale, 2mm in reality

Rectified

Levelled, parallel photos are taken under even illumination. Defined targets in the photos enable to rectify the image either by traditional darkroom techniques or more commonly using rectification software.

Rectified photos are suitable for 2-dimensional objects such as walls, wall paintings, stained glass windows.

The accuracy is dependent on the imaging scale and the flatness of the subject.

Conservation Photography

The majority of photography is used in conjunction with other work, such as restoration work. The metric or rectified images produced by the photographer form the base for mapping and graphical documentation. In many cases a professional photographer is brought on location at the beginning and the end of the project to record the before and after results. Large and medium format images are taken with the help of different lighting techniques to reveal the details, for example as seen in wall paintings.

Imaging for conservation and restoration will employ a wide range of formats and scales under different illumination set-ups depending on the content and purpose required.

Different illuminations are used to reveal (analyse) the material properties of the artwork e.g. raking light and UV/IR. The scale should be mostly 1:1. The imaging features should be documented with the image for repeatability.

2.4 Object characteristics

The wide range of objects within the historic environment like stained glass windows, wall paintings and sculptures, all have spectral characteristics of the materials used, such as glass, metal, sand and textiles, and creates a challenge for the photographer.

Size and scales

The size of the imaging object varies from several square meters to a macro detail.
The reproduction scale varies from 1:50; 1:10; 1:5 to 1:1

Film-based

For the standard architectural output scales of 1:50, 1:20 and 1:10, the minimum standard negative scales will be:
For 1:50 output scale, a minimum negative scale of 1:200
For 1:20 output scale, a minimum negative scale of 1:100
For 1:10 output scale, a minimum negative scale of 1:50

Digital-based

Where digital-based imagery is proposed the selected image resolution must allow an output resolution of at least 600 dpi and a pixel size that satisfies the output tolerances outlined here and later in this specification. For instance:

For 1:50 output scale, a maximum pixel size of 5mm in reality

For 1:20 output scale, a maximum pixel size of 3mm in reality

For 1:10 output scale, a maximum pixel size of 1mm in reality

Equipment

Camera, lenses

The choice of the camera format depends of the size of the imaging object, the available imaging distance, the required scale and therefore the required resolution.

Analogue Photography

Traditional film photography uses a range of formats. Large format cameras using sheet film commonly range from 9x12cm to 18x24cm and larger, and have camera movement facilities that enable the photographer to tilt and shift the lens and film panels to create high resolution images with rectified perspectives of architectural subjects.

Medium format cameras employ roll film with an image format ranging from 6x 4,5cm to 6x 9cm to produce high-resolution images. These cameras, including the VITRA image capture system, are frequently used for architectural photography using film and digital backs. Wider format medium-format cameras, 6x12 cm and 6x17cm, are used as panoramic cameras.

35mm SLR cameras with 24x 36mm imaging format are easily portable and are used for details and macro-photography.

Digital photography

Small format analogue cameras are not used widely because of the high quality and the operational comfort, of the digital Compact cameras. The CCD replaces the complete film level; therefore the imaging frame remains the same. The lenses keep the same focal length.

These cameras especially with their high light sensitivity and integrated flashes are an adapted good medium to document temporary information, e.g. a general survey at the first site visit, the settings during the imaging. The resolution is high enough to create images for Quicktime Virtual Reality™ panoramas. 30x 30cm, 24x 36cm, 37cmx 37cm are the size of the current CCD chips.

Digital backs

Digital camera backs can replace analogue film cassettes of medium-format (MF) cameras. They are compatible with most of the available MF-cameras. Existing difficulties in the adaptation had been solved by the modern MF- camera bodies. The format is decreased because of the size of the chip, the cameras built in electronics interface with the digital back. The camera images can be downloaded to Mac, PC or on certain manufactures equipment stored on the camera back data card. The photographer can then transfer this data to the computer. The Digital Backs provide their own software. The software is used to enhance the image quality.

Lenses

In professional photography fixed focal lenses are used, because the higher image quality and it eases repeatability. Lenses most commonly used are standard lenses 50mm (35mm format camera) equivalent to 80mm (medium size camera). Due to the large imaging areas wide angle lenses are often chosen for architectural photography.

Panorama photography requires wide-angle lenses to achieve the field of view, because of the software stitching process. Cubic imaging is used to overcome this problem enabling the user to view ceiling and floor. In the field of conservation photography Macro lenses helps to image at a scale 1:1 and even enlarged. For metric photography, the fixed focal length lens has to be calibrated. Digital imaging demands lenses with a high reproduction quality. Digital backs in connection with a medium format camera, with larger imaging frames than the size of the CCD chip, the focal length of the lenses is extended.

A standard 80mm lens will appear as a small Tele lens with an extension factor of about 1, 7. So no real wide-angle lens is at disposal, a disadvantage especially for the architectural photography.

Film

Professional films should be used to achieve consistent quality results, making sure that the films are developed and processed in a professional photographic laboratory.

Filters

Filters are not used in record photography, because the additional lens element introduces distortion, except for cut-off filters used in non-visible light spectra such as UV reflectography and IR.

Illumination

One of the most important parts in photography is the correct use of lighting. Reflective lighting is the standard method; transmissive illumination can be used for transparent materials like stained glass windows. To get a colour true reproduction, flash lights are preferred. A professional flash light system offers constant colour temperature of about 5600K over the entire power range. This changes in times and should be always controlled. The power of these units allows a short illumination time, this prevents light induced damage and is able to eliminate ambient light.

Individual adjustment of the two lights helps to create even illumination, especially when the lamps have to be positioned in different distances to the imaging object, due to location difficulties. Tungsten lamps are not used because they are with 2600K-2800K not day light balanced. The produced heat can damage the objects and is dangerous for the historic environment.

The created shadows under raking light purport a 3-dimensional image of the surface. For example, levels of paint layers, holes and flakes are visible and can be documented.

Depending on the imaging object the use of peripheral equipment such as reflectors, soft boxes can equalize the light fall off of the raking light illumination or difficult surface properties. Either side of the visible spectrum are like UV fluorescent photography and IR are useful tools in the field of conservation/ restoration.

A basic advantage of digital photography is that the camera, the lens and in particular the film do not have to be changed. The results can be checked immediately on displays (or a connected PC or monitor). With most of the small size digital cameras it is easy to create an UV image. The setting is like analogue photography. The sensitivity of the most digital camera backs is lower e.g. for the Jenoptik eyelike Precision M16 is 32 ISO. The following long exposure times up to some seconds causes problems at some cameras.

Camera Supports and Positions

Standard method of supporting the camera is a professional tripod. The capability of the head movement in all three dimensions enables non-distorted orientation of the camera. The reachable height of a tripod is 2.70m. Higher positions can be reached by lifting the equipment with a scaffolding towers (up to 15m), cherry pickers, cranes and telescopic masts (up to15m). Height is only limited by the constraints of the building.

Colour Reference Charts

Colour targets also need to be included in the image as well as measurement scales.
Standardised targets are used for calibrating a range of control parameters in the image capture system. These are normally reflective references printed on a sturdy card. These range from exposure control and colour calibration to measuring resolution for lens systems.

The simplest is an 18% grey card which reflects 50% of the light falling upon it. This is used to give an accurate light meter reading. This may be particularly useful in photographing objects under difficult lighting conditions.

These reference charts become an aid to the imaging process especially in the colour printing and digital imaging. The MacBeth colour checker was originally devised for the photographic film process and has 24-colour reference patches. Six of these represent graduated steps of grey from black to white. The remaining 18 colour patches represent the full-reflected gamut and includes skin-tone colours used as a colour reference for portraiture.

With the advent of digital photography, a new Gretag-MacBeth DC colour chart was devised with 237 reference colour patches. This increased number provides a larger data set of colours that helps to increase the analytical accuracy needed in digital colour reproduction. This chart is also use for measuring uniformity across its surface area.
All these charts can be placed within the field of view of the captured image. These charts are important references for colour matching and are used to achieve an accurate colorimetric image of the subject being photographed.

Setting the scene
The positioning of the camera and lighting will always be crucial in the imaging of historic monuments. With documentary photography, evenly lit images are the preferred way to record the subjects. This is usually supplemented with other capture methods to show the objects form and surface detail.

Determining exposure cannot usually be put down in table form because of the variety of materials under differing lighting situations. In practice there exists a proven standard setting the copy setting that creates the initial positioning. The final adjustments are worked out during the imaging on site.

Camera positioning
The distance of the camera of the object depends on the size of the image and the reproduction scale - if it is an overview or detail image. The scale affects the resolution of the image.

Positioning of lights
The distance of the illumination results from the size of the imaging object and the position of the camera. The position and angle of the illumination, to the imaging object is given by the surface properties such as matt, glossy or uneven.

Basic copy lighting comprises two balanced light sources positioned equally on both sides of the camera. Raking light visualise the surface texture, fabrication traces, layers and damages are getting visible and could be documented. Illumination used in this way could be used as a imaging tool for the forensic examination of surfaces.

Deviations from the standard techniques

Apart from the standard settings site realities, pillars, church furnishing prohibits the positioning of the equipment. Therefore the photographer needs to adjust the setting on site. If a large sized wall painting cannot be imaged as a whole, post image manipulation, stitching can be used. Any deviations can reduce the quality of the end product.

Monitoring/ Archiving

Repeatability is essential in historic documentation for monitoring the state of conservation of an object. The camera position, distance from object, lenses used, film type and any other external factors, the lighting system and arrangement should all be recorded in the file notes. The automation of storing this important information is embedded into the digital format. This metadata eases the requirement of repeatability.

At present the national archives requires black and white negative material along with colour negative and/or colour reversal for the archival characteristics. The integration of digital images is the new task.

2.5 Summary

This overview with the given examples shows the possibility of achieving a high quality "copy" of the object of art. With the different possibility of equipment and the setting the requirements of the clients can mostly be fulfilled. As location conditions and subject matter varies so considerable, it is impossible to give a fixed formula, which is where photographic expertise becomes paramount in the successful image capture. Techniques used for traditional analogue photography can be migrated to the digital imaging process with a few modifications.

The use of digital imaging has real advantages over the traditional wet analogue process in having the ability to see the image on site. This possibility of proofing the quality of the image and the required content is time saving. If the client is on site the images can be proved immediately or remotely through internet connection.

The highly accomplished standards of traditional architectural photography in situ encompass over 150 years of photographic expertise. Whilst it is easily possible to use digital image processing to make corrections to captured images, this should not be a tool for correcting badly taken images.

Digital imaging is a relatively new medium that currently compliments but not yet supersedes film photography. There are advantages and disadvantages to both systems depending for example on application, required resolution, cost, archival stability, portability and accessibility. It is likely that further advances will be made in the forthcoming years that will improve the possibilities of direct digital capture.

3. THE IMAGE PROCESSING CHAIN

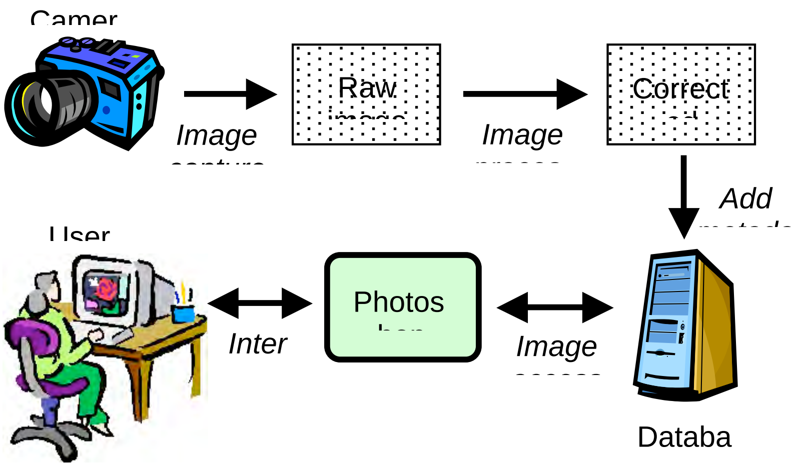


Figure 1: Flow of images in the VITRA system.

3.1 Overview

The VITRA image-processing chain consists of a sequence of image processing operations from the 'raw image' output by the camera to the 'corrected image' stored in the database. These operations are designed to normalise the image data into a standard form suitable for subsequent applications. Figure 2 shows a schematic diagram of the processing chain. The tasks can be grouped into four stages:

Initial image capture, storing pixel data from the camera as the ‘raw image’;

Correction for the tone reproduction characteristics (scene luminance to signal transfer function) of the camera, and correction of the spatial non-uniformity of the illumination and lens transmittance, resulting in a tone-corrected image;

Correction for any chromatic aberration and geometric distortion introduced by the lens, followed by compensation for any losses in sharpness due to the lens or image sampling, resulting in a spatially-corrected image;

Conversion of sensor RGB image data into a colorimetric space (XYZ) and thence into a uniform colour space (CIELAB), followed by encoding into the database storage format and addition of a header containing metadata and profile for colour management.

For several of the camera calibration procedures it would be feasible to employ a light-weight rotating arm on the robotic carrier to move a suitable chart/grid in front of the camera at a specified distance to provide a reference target. It is desirable, however, that such calibration procedures should be predetermined in the laboratory rather than on-site.

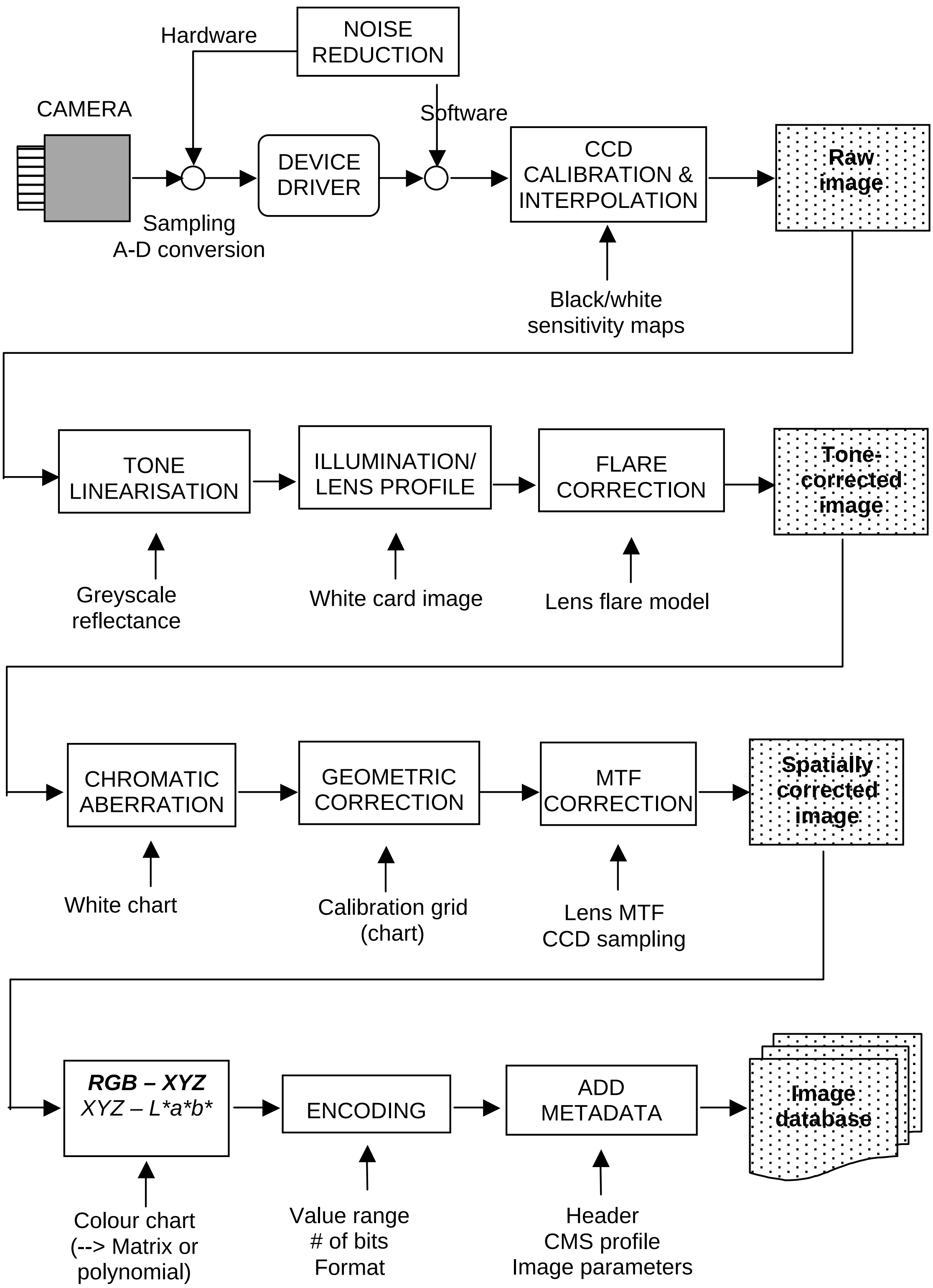


Figure 2: Sequence of operations in mage processing chain.

3.2 Image capture

The VITRA image capture is achieved by the Jenoptik eyelike Precision digital back on a Rollei AF medium-format camera body. The Kodak sensor has 4096x4096 pixels, with an integral colour filter array. The functions of noise reduction, CCD calibration and pixel interpolation are performed within the camera and/or device driver. The resulting 'raw' image from the camera may, if desired, be stored directly in the database.

Noise reduction

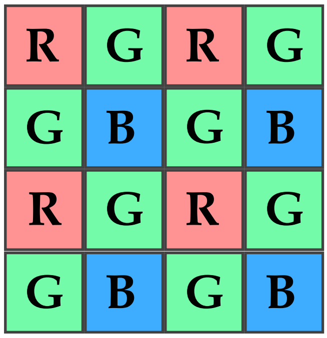
Noise reduction takes place at two different points. At the hardware level, it is necessary to reduce and stabilise the temperature of the CCD sensor (achieved by Peltier cooling within the digital camera back) and in the analogue electronics (double-correlated sampling, etc.). More sophisticated noise reduction can be performed on a software level, which requires some knowledge of the nature of the various noise sources involved, i.e. shot noise, thermal noise, etc. Integration of multiple exposures can also be used to minimise noise.

CCD calibration

It is necessary to ensure that each photosite in the CCD sensor generates the same signal given the same photonic input. Black calibration (lens cap covering lens) is normally done within the device driver software to correct the 'floor' level of each photosite. White calibration data is acquired by flooding the sensor with uniform white light (removing the lens or heavily defocusing the lens with a white card in front of the camera), and is used as a gain factor to normalise CCD sensitivity.

Pixel interpolation

In the 'one-shot' mode, which will normally be employed for VITRA photography, the pixel data obtained from the CCD array is arranged into RGB components according to the Bayer pattern of the colour filter array. Thus along any row or down any column the data alternates between red and green or between blue and green. In order to obtain a true 4Kx4K image, the software must interpolate between the nearest four pixels in each of the three RGB channels. Also the removal of 'dead' pixels and columns is usually done within the driver, using defect data coordinates supplied by the CCD manufacturer.



3.3 Tone correction

Tone linearisation

For accurate image capture it is essential to know the tonal relationship between the surface reflectance and the signal generated by the camera, which is generally non-linear (for the Jenoptik camera it is approximately a square-root function). The transfer function can be determined by fitting a suitable function, such as piece-wise linear or polynomial, through the average digital values obtained from a series of achromatic (grey-scale) patches of known reflectance, e.g. in a standard photographic test target or colour chart such as the Macbeth Color Checker. Tone linearisation can then be achieved by applying the inverse function to the digital data from the camera1.

Luminance uniformity

Radiometric variations in the image may be caused by non-uniformity of the luminance distribution in the surface and off-axis losses in the lens (vignetting). Inhomogeneity of the sensor array (pixel-by-pixel variations in CCD sensitivity) is assumed to have been corrected already within the device driver. For white level correction it is necessary to capture an image of a white surface of uniform reflectance (90% or higher). Lens transmittance and luminance profile combined can then be fitted by a smooth two-dimensional function spanning the image area, which can then be employed multiplicatively to correct the image on a pixel-by pixel. This operation can be done in the laboratory for each lens, but will generally need to be performed on site for each illumination configuration, so the correction may be a composite of two separate profiles.

Ambient light and flare

Ambient light is the level of (generally diffuse) illumination present in the environment, which is not produced by the illumination system. Its effect is additive to all tones, thereby raising the black level, which thus may substantially reduce the dynamic range of the image. The ambient level within the building may be particularly problematic for back-lit transmissive images of stained glass, unless some physical means can be found to prevent it falling onto the area of the surface being photographed, e.g. by a hood or shroud around the camera. The effect of ambient light level can be approximated by capturing an image of a white card in surface plane, smoothing to remove noise, and subtracting from wanted image.

Flare is the spill-over of light from bright areas of the image into dark ones, produced by diffusion and multiple reflections from the optical surfaces within the lens. It is reasonable to expect that, regardless the quality of the optics, a certain amount of flare will always be present, especially in very luminous scenes and at high-contrast edges within an image. It will be necessary to assess the extent of the problem with the camera and lenses selected for VITRA, and to investigate the current research and solutions available.

3.4 Spatial correction

Chromatic aberration

Chromatic aberration is the spectral separation of colours in the image plane due to dispersion of different wavelengths in the lens elements. It is usually most noticeable at the edges of the image and may change with different lens aperture (f-stop) settings. It can be characterised for each aperture setting of a particular lens by imaging a white grid on a black background to fill the image plane. Experimentation will show whether it is a significant problem for the very high quality lenses to be used with the VITRA camera.

Geometric transformation

Geometric distortion may be introduced into the image by: (a) an imperfect lens, (b) a non-planar surface, or (c) the axis of the lens being non-perpendicular to the plane of the surface. By modelling each of these factors, a suitable algorithm could correct the resulting geometric distortions. The distortion inherent in the lens can be determined in the laboratory by imaging a rectilinear grid of lines or points. The surface and imaging geometry, however, can only be determined on-site with the camera in the position selected by the operator. For this purpose, some photogrammetric method and/or spatial calibration target (e.g. a ruler or graticule) is required to establish the orientation and topography of the surface.

MTF/sharpness

The modulation transfer function (MTF) of the optics and CCD sampling array set the limit on the fineness of surface detail resolvable by the camera. Ideally the spatial frequency at which the MTF of the lens falls to 30% of its maximum value should exceed the Nyquist limit of the array (2 pixels). This can be established by laboratory imaging of a suitable calibration target, such as a set of sine-wave patterns of variable spatial frequency or a slanted edge2. Losses of image sharpness can be compensated by application of a suitable convolution filter, such as an unsharp mask (USM). The objective should be only to compensate for losses in sharpness, not to increase the sharpness excessively.

3.5 Colour correction

White balance

For VITRA imaging where the sole source of illumination is provided the system (reflective or transmissive), it is possible accurately to characterise the spectral power distribution function of the light source and hence to determine its correlated colour temperature and the white balance for the camera. White balance is expressed as the ratio triplet R:G:B of the camera's output signal values when imaging a white card. The ratio can be used to normalise the camera output for all other colours (after tone linearisation) so that for white all channels would be at maximum value (or at the value selected to represent white, which may be less than maximum signal value if the representation of specular highlights is required).

Accurate estimation of unknown illumination conditions, however, represents a real challenge for image processing. This would be the situation with daylight illumination of stained glass windows, or ambient illumination of interior reflective surfaces. If a spectroradiometer were supplied with every VITRA system, then suitable measurements could be made in each case, but this is impractical for both cost and operational reasons. Intelligent algorithms, together with standard colour charts, will be required in such cases to determine the correct white balance. One possible solution is to adopt supervised post-editing strategies, where the user specifies the colorimetric characteristics, or 'preferred' rendering, of some areas in the image. However, it is still unclear how to tackle the general problem in absence of data, and how to obtain at least partial measurements at a reasonable cost.

Colour characterisation

It is necessary to characterise the colour response of the camera's three-band filters plus sensor so that the RGB image data can be related to the colorimetry of the surface being photographed. There are broadly two methods of doing this. First, an adjustable monochromatic light source can be used to measure the sensitivity of each channel directly at each wavelength throughout the visible spectrum. Second, a test chart in which the spectral reflectance distribution of each colour patch is known (by prior measurement with a spectrophotometer) can be imaged by the camera under a source of illumination of known spectral power distribution and the average response of the camera to each colour patch determined. In this case a regression procedure can be used to generate polynomial functions which give a good estimate of the camera's response to any input colour3. To a first approximation, a simple 3x3 matrix (i.e. first-order polynomials) may be used to convert RGB camera signals to XYZ tristimulus values.

Colour space

Once the VITRA system (camera plus illumination) has been characterised for a particular class of colorants (dyes or pigments), the question arises how to process the image. One method is to convert the RGB image data immediately via XYZ into a device-independent colour space, such as CIELAB, and store it in this form in the database. An alternative method is to retain the image in the (white balanced) RGB camera data and to embed in the image header a 'profile' containing enough information to allow the receiver or later user of the image to interpret the colorimetric meaning of the data. This is the method developed over the past decade by the International Color Consortium (ICC), and widely used in colour management systems4.

CIELAB has the benefit of being (approximately) a perceptually uniform colour space. Algorithms that exploit the topology of the colour space (i.e. segmentation, classification, mosaicing, etc.) may benefit from such a uniform colour space, with orthogonal dimensions and co-ordinates that correspond to perceptual units.

3.6 Transfer to database

Encoding

Before being stored in the database, the image data must be properly encoded. For most purposes it should be sufficient to use 8 bits/channel (24-bit colour depth), however the possibility must be considered for high-quality archival images of using an extended 16 bits/channel representation. VIPS software from the National Gallery uses a packed data format of 32 bits/pixel with 10,11,11 bits respectively for the L*,a*,b* components, developed in the MARC project especially for storage of images of canvas paintings5. In order to exploit the full dynamic range of the data representation, i.e. to minimise the number of unused code values, the range of values per channel (i.e. min/max value) must be provided. This is particularly true for the CIELAB representation, where the typical range of values may be different for each channel (e.g. L* 0 to 100, a* -70 to +80, b* -50 to +90) and depend on the gamut of the colorants6.

Metadata

A suitable set of metadata must be attached to each image file. These metadata may record the name, location and time at which the picture was taken, together with higher-level information such as a CMS (Colour Management System) profile, camera parameters, information on the illumination, etc. If the image is part of a set of multiple images or of a panoramic scene, any parameters that must subsequently be used by the image processing algorithms will also be attached. A pointer may be included to 'batch' information which applies to a large number of images, such as the name of the site, photographer, date, job number, etc. Such data may be stored separately in the database.

4. conclusions

This paper has given an overview of initial considerations required for the direct digitisation of decorated architectural surfaces. This will be applied in the VITRA project to create a robotic capture system that can reach 15 metres above ground level. The challenges are considerable in producing an operational system that will complement the existing repertoire of skills of a professional photographer. Through the VITRA project new capabilities are being developed for the digital image capture in situ of colorimetric heritage images. By using standard “components off the shelf” (the COTS philosophy) we are ensuring high-quality image acquisition, with excellent illumination, camera body and lenses. Our efforts are being concentrated on the upgrading of a digital camera back with CCD sensor, construction of a versatile and novel robotic carrier, and the development of image processing algorithms. These algorithms will normalise the images to achieve optimum quality for storage in the database, followed by functions adapted for use by conservators within a familiar Photoshop imaging environment. We believe that this approach will enable very cost-effective results to be achieved by the project. The system will be extensively evaluated during the fourth quarter of 2003 and the first quarter of 2004 by professional heritage users at six sites in both Germany and the UK.

REFERENCES

MacDonald, L.W., Giani A., Veridical Imaging of Transmissive and Reflective Artefacts”, EVA Conference, London, July 2003.

MacDonald, L.W., and Ji, W., ‘Colour Characterisation of a High-Resolution Digital Camera’, Proc. Colour in Graphics, Imaging and Vision (CGIV), University of Poitiers, France, pp. 433-437, April 2002.

Bouzit, S., and MacDonald, L.W., ‘Modelling the Modulation Transfer Function of Various Imaging Devices’, Proc. IS&T PICS Conf., Portland, pp. 130-135, April 2002.

MacDonald, L.W., Ji, W., Bouzit, S., and Findlater, K.D.M., ‘Characterisation of a Digital Camera for Heritage Photography’, Proc. Intl. Congress of Imaging Science (ICIS), Tokyo, pp. 345-346, May 2002.

International Color Consortium, File Format for Color Profiles, available for download from http://www.color.org/icc_specs2.html

MacDonald, L.W., ‘Image Representation and Colour Separation in the MARC Project’, Proc. Electronic Imaging and the Visual Arts (EVA) Conf., London, July 1993.

MacDonald, L.W., and Deane, J.M., ‘A Comparative Study of the Errors caused by Quantising Colour Images’, J. Phot. Science, Vol. 41, No 3, pp 106-107, 1993

Findlater, K.D.M., and MacDonald, L.W., ‘Fieldwork at Christchurch Cathedral, Oxford’, Report #4, AHRB project Direct Digital Image Capture of Stained Glass, University of Derby, Appendix by John Cupitt, pp. 37-39, 2002.

Debevec, P.E., and Malik, J., “Recovering High Dynamic Range Radiance Maps from Photographs“, Proc. SIGGRAPH, 1998.

Giani, A., MacDonald, L.W., Machy, C. and Suganthan S., 'Image segmentation of stained glass', Conf. on Color Imaging VIII: Processing, Hardcopy, and Applications, Santa Clara, Proc. SPIE, Vol. 5008, pp. 150-158, January 2003.

MacDonald, L.W. and Oldfield J., 'Image Capture and Restoration of Medieval Stained Glass', Proc. Fourth IS&T/SID Color Imaging Conf., Scottsdale AZ, pp. 44-49, Nov.1996.

Malzbender, T., Gelb, D, and Wolters, H., 'Polynomial Texture Maps', Proc. SIGGRAPH, pp. 519-528, 2002.

Findlater, K.D.M., Schick B., Beckett, N., "Imaging Architectural Sites for Conservation and Archive", Digital Heritage Ch.7, Ed. MacDonald L.W. (to be published in 2004).

English Heritage, "Metric Survey Specification for English Heritage", published by English Heritage, National Monuments Record Centre, Great Western Village, Kemble Drive, Swindon SN2 2GZ. May 2000.