Imaging the Banqueting House Ceiling

John Hallett-Jones, Director of Glanville Geomatics, describes a new technique for high-resolution imaging of historical objects like ceiling paintings and mouldings where sub-millimetre pixel resolution is called for.

Over recent years, heritage recording has undergone massive change. Improvements in terrestrial scanning, digital imaging and the ability to navigate these datasets using mobile devices has provided the surveyor with a wealth of new opportunities to deliver quantitative and qualitative information at a resolution never before commercially achievable.

In order to provide a cost-effective approach to digital recording to the historic sector, we highlight a technique developed to swiftly capture high-resolution seamless imagery using an affordable small format DSLR (Digital Single-Lens Reflex) camera platform. This technique, known as automated panoramic imaging, makes use of a DSLR camera mounted on a computer-controlled 360° motorised head.

Glanville Geomatics has been using this technology for the recording of highly detailed subjects, such as ornate ceilings, tapestries and fine artwork, where sub-millimetre pixel resolution imagery is required and is more critical than image geometry. These images provide a valuable resource for the monitoring of condition, cataloguing, conservation management and visual media. Production of a seamlessly blended image that is fit for purpose, economic to produce and navigable does however firstly involve overcoming many practical obstacles.

Resolution

We use scale to categorise vector products but for raster products we generally use the term resolution. The measure of resolution is the ability of a sensor to define small objects with clearly defined boundaries. However, what constitutes an optimum resolution will often be driven by the end user requirement and may well be specified in terms of what size the pixel represents in the real world. This real-world pixel resolution, or ground sample distance (GSD), is a very useful starting point when undertaking such imagery.

It is, however, important to clarify resolution with regard to a typical DSLR sensor. Image resolution can be described as the number of pixels that the sensor will contain. For example, a 24-Mpx camera will contain 24 million pixels. Each pixel may be limited in what it can or cannot record in the visible spectrum. Indeed, a smaller pixel area may compromise the sensor's dynamic range, thus reducing the clarity of the information available.

Although the subject of resolution drifts into the realms of unspeakable equations and graphs, it can be summarised by saying that a camera with a higher pixel count may not necessarily provide a sharper image. It is therefore necessary to select a camera and lens combination that has optimum spatial resolution characteristics.

Take for example, a typical 24-Mpx DSLR camera sensor with a sensor size of 36 × 24mm. The size of each pixel, in real-world terms, would translate to 0.15mm if captured with a 400mm focal length lens at a distance of 10m. If the focal length is increased, or the platform is moved towards the subject, then the real world pixel size decreases still further, but with the downside that the image coverage decreases.

For this article, we shall concentrate on a ground sample distance of between 0.25 to 0.05mm (4 to 20 pixels per mm), which is well suited for the recording of plane objects such as paintings, tapestries and ceilings.

A Seamless Image

Close-up images are often not that useful in isolation, especially on a large subject. To overcome this, one approach is to take multiple images and then stitch them together. If you can stitch hundreds of images together you have the ability to create a homogenous image with very high visual resolution.

To obtain a nominal GSD of 0.15mm, a 24-Mpx camera platform with a 400mm lens would cover a real-world area of 900 × 600mm at 10m. Add to that the need for adequate overlap between frames – more than 30% for reliable stitching – and the image numbers soon stack up; a total of approximately 150 over a typical tapestry, painting or ceiling of, say, 8 × 5m. If a GSD of 0.10mm is required, the number of photographs needed increases to nearer 400!

At this stage it is worth introducing the concept of a seamless image and what it actually represents.To obtain a seamless image in this way, the parallax between frames needs to be eliminated (parallax is that movement of two distant objects relative to one another when

viewed from different viewpoints). For stereo imagery, parallax is a key consideration, but for the single set-up giga image this must be eliminated or at least mitigated to negligible values.

To mitigate the effects of parallax, the camera's focal point should be coincident with the origin of rotation at all times. The camera is mounted on a rotating pan head and the focal point of the lens is adjusted to ensure that it is positioned at the centre of rotation during the shoot. The subject is then imaged in a series of predefined horizontal and vertical angular increments about these axes, after which the resultant images can be seamlessly stitched together.

With 360° panoramic and -65±90° tilt range on the camera head, it becomes apparent that the imagery is being projected based upon a spherical projection, with the result that the GSD will increase towards the perimeter of the subject with the optimum GSD at the centre, orthogonal to the surface. By balancing the subject-to-camera distance and the focal length of the camera, this can be optimised by using a nominal GSD value that minimises changes across the subject area, in a similar way that map projections aim to minimise scale change.

Once the resolution is determined, along with the distance to the subject, the mechanics of the shoot are relatively straightforward. However, there are environmental considerations that must be addressed before the images are taken, to ensure that the resultant image is blended well in terms of light, colour and sharpness.

Lighting

Lighting is an environmental factor that has to be controlled with great care when undertaking multi-imaging. A diffuse natural light is often preferred but it has to remain constant during the shoot. If the shoot is likely to take a few hours then natural light can easily vary, not only in intensity, but also in temperature. If this occurs the resultant images may have varying exposures or have a colour temperature change that is difficult to accommodate in post-processing.

To overcome this, it is often better to have control of the light, to ensure that it remains constant and to customise the white balance and exposure before the shoot. Of all the technical aspects, this can be the most challenging.

Capturing Rubens

The Banqueting House in Whitehall was built between 1619 and 1622 and stands as the only remaining part of the Palace of Whitehall in central London. It is cared for by an independent heritage charity, Historic Royal Palaces, and is a fine example of the architecture of Inigo Jones.

For a recent project, the challenge was to provide high-resolution imagery of the 550 sq metres ceiling of the Banqueting House, to increase understanding of the workmanship and condition of both the ceiling structure and the artwork. The ceiling itself is not an ideal planar surface and is heavily moulded by the coffers that house the nine Rubens paintings, making the project particularly awkward.

With a floor to ceiling height of 16m, each of the nine ceiling panels had to be imaged with a ground sample distance of no greater than 0.25mm. Fixed scaffolding was not an option, and all the work had to be carried out during the working day in a space open to the public. As a result, a ground-based mobile camera platform, that could execute rapid imaging, was deemed the only viable solution.

The set-up consisted of a Nikon D800 camera with a 400mm prime lens, mounted on a stable tripod and panoramic head. Linked to the head was a laptop controlling the camera and the head and providing a means for rapid download. A total of nine set-ups were planned, with each one located directly beneath the centre of each panel. This resulted in nine separate giga images covering the 34 × 16m ceiling area.

With work undertaken during daylight hours, the initial challenge was to plan for a cloudy day in order for the light to be as diffuse as possible. The artificial lighting within the room was, for the main part, the dominant light source and luckily the influence of external light changes did not adversely affect the final images.

The camera's white balance was set to best represent the colour temperature and then kept constant throughout the shoot. Exposure was also gauged across the subject and again kept constant throughout.

Finding the Sweet Spot

The lens aperture was set to the lens "sweet spot" to minimise lens aberrations and diffraction and to ensure an adequate depth of field on the coffered ceiling. There is a trade-off to be had here: if the lens aperture is too small, exposures have to be long, if it is too big, the depth of field is reduced and that may introduce poor focus in peripheral areas. With hundreds of images to capture, and the need for a rapid shoot to minimise potential changes in the ambient light, the balance between these parameters required careful planning from the outset.

In addition to this, working with larger, heavier lenses can cause panoramic head vibration during the shoot and thus extra time between frames was factored in to dampen these effects and ensure focus was kept crisp. Once the camera was set, then the image spacing, overlap and field of view were configured on the panoramic head via the PC interface in order to achieve the desired coverage.

Once activated, the system captured the images in a series of angular steps. Each one was downloaded both as a raw file and as a jpg for review. If an image looked poor, for whatever reason, the panoramic head was programmed to return to that position and retake the photograph.

Post-capture, the images were passed through Adobe Lightroom to calibrate the camera's colour and to undertake a quality check. The image set was then blended and stitched within the dedicated panoramic software, which automatically creates a database of common points between images providing a statistically robust fit between adjacent frames. The panorama is then adjusted to suit a planar projection.

Viewing the Imagery

Having captured and compiled the imagery, the next hurdle is viewing the image. With such large files (often greater than 2 gigabytes), typical navigation through the image can be slow. By breaking the image up into tiles, the panorama can be navigated by using only those tiles relevant to the screen. This can be uploaded as an offline HTML5 file for navigation either to a PC or iPad platform or by streaming the images through an online resource.

By adopting this multi-image approach, Glanville has provided high-definition imagery for the 550 sq metres ceiling, precisely stitched together to create nine seamless gigapixel images with each pixel representing 0.25mm of real-world information. That's a total of nearly 11 billion pixels of history.

The images show incredible detail, including cracks, brush strokes and minute flaking, enabling the conservators, archaeologists and surveyors of the fabric to catalogue, monitor and help preserve the nation's treasures in a manner never previously achieved. Glanville's work is the first part of a major project for Historic Royal Palaces to conserve and represent the Banqueting House over the next five years, in time for a re-launch in 2019 to celebrate the 400th anniversary of the commencement of Inigo Jones's work on the building.

The approach has been challenging and the learning curve has been steep, when dealing with all the varying parameters. The environmental considerations and the decisions on the most appropriate hardware to match the budget have led us down some interesting pathways. More recent projects have included the recording of the Tapestries at Hampton Court, where an even finer level of detail was required (0.15mm resolution), the Queen's Stair ceiling also at Hampton Court and the Privy Chamber ceiling at Kensington Palace at 0.2mm resolution.

The technology does not just stop at the recording for historic features. Applications to capture cityscapes, landscapes and even construction sites, all lend themselves to this rapid and affordable technology. Introduce the fourth dimension of time and the system becomes a very powerful cost-effective and mobile recording tool.

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