Gigapixel Frame Images

Is the Holy Grail of Airborne Digital Frame Imaging in Sight?

Over the last few years, there has been much interest in and considerable publicity about the production of digital frame images that are Gigapixel in size. This interest has been apparent both among amateur and professional photographers at one end of the imaging community and among scientific astronomers at the other end. This article reviews the technical developments that have taken place to allow Gigapixel images to be generated. It also discusses the possible implications for the geoinformatics industry, especially those involved in airborne photogrammetric and remote sensing activities.

by Gordon Petrie

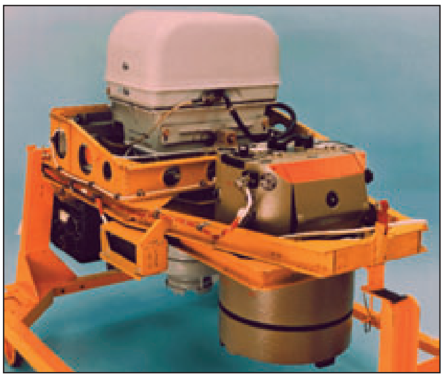

Figure 1a: A Hycon HR-732 large-format camera (at the rear) and a Leica RC10 standard-format camera (at the front) sitting on a dual camera mount - as operated from high altitudes from one of NASA's ER-2 aircraft. (Source: NASA)

Airborne Digital Frame Imagery

In particular, the author looks at the possibilities of applying these new technologies and developments to overcome the limitations in the size of the CCD area arrays that are being used currently in airborne digital frame cameras. These limitations have resulted in the use of multiple cameras to generate large-format digital frame images. However, even then, the resulting images are still comparatively small in size - around 80 to 100 Megapixels.

Part I (in this issue) will discuss the developments that have taken place to produce Gigapixel images within the area of amateur and professional photography. Part II (to be published in the next issue of GeoInformatics) will discuss the corresponding developments in the field of scientific astronomical imaging. In both parts, an analysis will be undertaken with a view to assessing their potential application to the acquisition of digital airborne frame imagery.

Four Main Approaches

Within the particular area of Amateur & Professional Photography, four main approaches can be identified, each of which will be explained further in this article.

(1) First of all, Gigapixel images have been generated using large-format photographic cameras to acquire frame images of the required scene on negative film. After development, these photographs have then been scanned using a high-resolution photogrammetric film scanner to generate the corresponding digital images.

(2) A second approach has been to use a small-format digital frame camera equipped with CCD area arrays to acquire numerous overlapping frame images of a large area in a systematic and controlled manner. These images are then stitched together using image processing techniques to generate a composite mosaic forming a single panoramic image of the required scene that is Gigapixel in size.

(3) A third approach has been to utilize specially built or modified frame cameras that acquire digital images of the scene directly through systematic scanning of the required area across the focal plane of the frame camera using CCD linear arrays. Again the application of this technique can produce Gigapixel-sized images.

(4) A fourth approach has been the generation of digital panoramic frame images using newly-developed rotating line scanners, again based on the use of linear arrays. The largest of the resulting images are again Gigapixel in size.

Large-Format Film Cameras

The basic technology of the large-format film frame camera is of course quite well known to those photogrammetrists and photo-interpreters who have been working in the defence mapping and intelligence fields during the last 30 to 40 years. Taking a well-known example, during the 1970s, the American Itek company produced its range of Metritek photogrammetric film cameras equipped either (i) with an f = 12 inch (30 cm) lens and producing photographs with a 9 x 18 inch (23 x 46 cm) format; or (ii) with an f = 8.25 inch (21 cm) lens producing 9 x 13.5 inch (23 x 34.5 cm) format photographs. Using high-resolution Kodak 3414 black-and-white panchromatic film, aerial images with resolution values of 75 to 80 line pairs per mm were achieved using these cameras. They were usually operated at altitudes up to 60,000 ft. (20 km) or even higher on-board RB-57 or U-2 reconnaissance aircraft. Other versions of this type of film frame camera with the 9 x 18 inch format were developed by Hycon. For example, the company's HR-732 camera is equipped with an f = 24 inch (60 cm) lens and has been used extensively by NASA, flown on its civilian (ER-2) versions of the U-2 aircraft, see Figure 1(a). The Itek Metritek 30 was developed still further for use in space in the form of NASA's Large Format Camera (LFC). This was flown on-board Space Shuttle mission 41G in October 1984. Over 2,000 photos from this mission are still available from the EROS Data Center (EDC) in Sioux Falls in both hard-copy and digital form. Indeed the EDC offers the black-and-white LFC photos scanned either at a 14µm pixel size

Figure 1b: Two different versions of the Fairchild large-format film cameras that have been modified for use in the Gigapxl Project - with the long (18 inch) side set in the horizontal position in the example on the left of the picture and set in the vertical position in the example on the right. (Source: Gigapxl Project)

(giving a file size of 2 x 262 Megapixels) or at a 7µm pixel size (producing a 2 x 1.3 Gigapixel file). The LFC colour and false-colour photographs are offered with the 14µm pixel size only, resulting in a file size of 2 x 787 Megapixels.

(a) Gigapxl Project

This began in 2000 as a retirement project carried out by Graham Flint (a physicist and optics specialist from the U.K. who had worked in senior positions with Lockheed and the USAF) and his wife, Catherine Aves (with a background in desktop publishing and image processing) who are now based in New Mexico. They decided to build a very high-resolution camera that could be used on the ground to record large-format digital images of the landscapes of North America. To obtain the very detailed yet wide-angle images that they desired, they constructed a purpose-designed camera on the basis of an old Fairchild K-38 large-format aerial film camera - again having a 9 x 18 inch (23 x 46 cm) format. The main body and the magazine were retained, but many modifications were made to the rest of the camera. In particular, a new wide-angle (Asymmagon) lens with f = 215mm was designed and manufactured to meet the specific requirements of landscape photography using this camera, see Figure 1(b). A new lens mount, together with a precision tilt and focus mechanism, was also purpose-built for the camera. The film drive motors were stripped out to save weight and the camera converted to manual operation. The camera was then fitted inside a specially-built skeletal metal frame which sits on top of a sturdy and stable tripod. A small-format Nikon digital camera was mounted on this frame to act as a viewfinder, supplementing a telescopic sight.

After exposure in the camera, the large-format negative film images are scanned either in a Leica Geosystems DSW500 or a Vexcel VX-4000DT film scanner. Initially a 12.5µm pixel size (providing 80 pixels per mm) was used, producing digital images that are 670 Megapixels in size. Since then, collaboration with Leica using its latest DSW700 scanner has resulted in the capability to scan the film with a smaller 6µm pixel size resulting in a file size of 2,900 Megapixels (2.9 Gigapixels). The colour photographs of the 1,000 or so landscapes that have been imaged so far have mainly been taken using the Kodak SO846 and 2444 and the Agfa Aviophot aerial colour negative films that are very familiar to photogrammetrists. However high-resolution black-and-white panchromatic films have also been used for the purpose.

The final colour images were produced originally on a Cymbolic Sciences (now Océ) LightJet 5000 printer using Kodak professional colour paper. More recently, the images have been produced on an Epson Stylus 9600 colour printer. A very detailed account of the design and construction of the Gigapxl camera, together with a fascinating in-depth analysis of its performance and numerous eye-catching sample images can be found on the project's Web site: http://www.gigapxl.org/.

Figure 1c: The Ross R1 large-format film camera being used to expose a photo of Mount Sopris in Colorado (Source: Clifford Ross)

(b) R1 Camera

Following on from the Gigapxl Project, starting in 2003, a similar approach to the generation of Gigapixel images has been taken by another American artist and photographer, Clifford Ross, who is the principal of Ross Studios in New York City. The basis of his R1 camera is again an ex-military Fairchild film frame camera producing a 9 x 18 inch (23 x 46 cm) format photograph. The camera has been modified to sit in a specially built cradle which is mounted on a heavy-duty tripod, see Figure 1(c). The R1 camera utilizes colour negative film - in this case, Fujichrome Velvia - which, after development, is scanned in a high-quality film scanner to produce a 2.6 Gigapixel digital file. As with the Gigapxl Project, the final colour image is output on an Océ LightJet printer. The relevant Web site - http://www.cliffordross.com/ - is again quite voluminous, though it is a little less informative on the technical aspects of the camera and has a greater concentration on the more artistic and interpretive aspects of the resulting imagery. In December 2004, Ross formed a working group, including participants from the Sandia National Lab, New York University and several commercial companies, to investigate further the display and interpretive aspects of his large-format high-resolution digital images employing wall, ceiling and floor projection techniques.

Composite Image Mosaics

Two examples of this alternative approach to the formation of Gigapixel images that have used multiple small-format digital images are the projects undertaken by an American photographer, Max Lyons, and by the Dutch research organisation, TNO.


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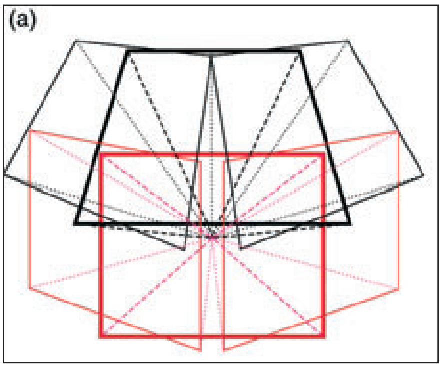

Figure 2a: A diagram showing the geometric arrangement of a block of overlapping concentric frame images acquired by a single digital camera from a single exposure station. (Drawn by Mike Shand)

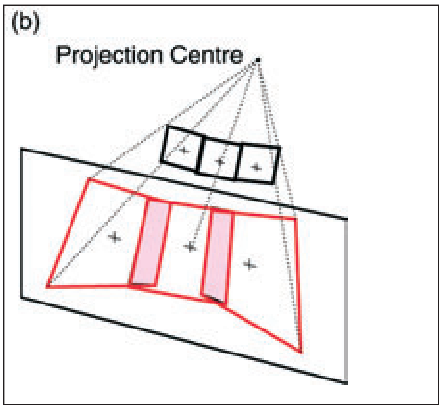

Figure 2b: The overlapping concentric frame images can be projected on to a common plane using a 2D projective transformation. (Drawn by Mike Shand)

stored on a laptop computer. The final image processing - including the stitching together and merging of the individual images - was carried out using the same software packages and tools as Max Lyons. However various additional software modules had to be developed by TNO for the automated control of the camera motions. Furthermore while Max Lyons carried out the stitching together of the images purely manually, the TNO group used a highly automated approach. A detailed account of the TNO project, together with numerous photos of the equipment, the location and extracts from the final image is given on http://www.tno.nl/gigapixel/.

(a) Max Lyons

Max Lyons is a professional photographer based in Washington, D.C. who specializes in taking panoramic photographs of building interiors and exteriors and of landscapes from multiple overlapping images acquired by a small-format frame digital camera. He has also developed a number of software tools to aid the construction of the final composite large-format panoramic images formed from the numerous individual overlapping small-format images taken by the camera. An example of his work that has received wide publicity is the panoramic image of Bryce Canyon in Utah that was generated towards the end of 2003. This composite image has been constructed from 196 individual frame images, each 6 Megapixels in size. These were taken using a Canon D60 digital camera equipped with an f = 280 mm lens. The camera was mounted on a Manfrotto tripod equipped with a special head that allowed it to be rotated around the nodal point of its lens. This allowed the images to be taken in a systematic manner along each of several rows with small overlaps between them, see Figures 2(a) & (b). The image processing was carried out over several days using Adobe Photoshop in combination with specialized software (Panotools and PT Assembler) to carry out the matching and stitching together of the individual images. The dimensions of the final mosaiced image of Bryce Canyon are 40.7k x 26.8k pixels = 1.09 Gigapixels. The size of the compressed colour RGB file was just over 2 Gigapixels. More information is given on the relevant pages of Max Lyon's Web site - http://www.tambaware.com/maxlyons/gigapixel.htm.

(b) TNO, The Netherlands

In the autumn of 2004, the Dutch TNO research organisation also followed the same general approach by using a relatively inexpensive small-format digital camera to take multiple overlapping images from the top of a 100m high building in the town of Delft to produce a panorama of the town and the surrounding countryside. It then carried out the stitching together and merging of the resulting multiple images to create a single composite mosaic image that is 78.7k x 31.6k pixels = 2.5 Gigapixels in size. The file size of the final RGB colour image was 7.5 Gigapixels. The TNO group used a Nikon D1x digital camera equipped with an f = 400mm lens that produced individual images that are 6 Megapixels in size. This camera was mounted on a Manfrotto tripod that was fitted with a computer-controlled pan and tilt head equipped with motors, encoders and a motion controller, see Figure 2(c), instead of the manually operated head used by Max Lyons.
A total of 600 individual images were acquired, with each image being read out and

Figure 2c: The Nikon D1x small-format digital camera with its motorized pan-and-tilt head and motion controller hardware mounted on the parapet of the 100m high Electrical Engineering building of the Delft University of Technology to order to acquire the photos of the town. (Source & Copyright: TNO)

Frame Cameras with Scan Backs

As the photogrammetric community is only too well aware, currently the largest CCD area arrays that are readily available commercially to acquire colour images are 4k x 4k pixels = 16 Megapixels or 5.4k x 4.2k pixels = 22 Megapixels in size. Most of these area arrays are manufactured by Kodak. These arrays are used for example in the digital backs fitted to the Applanix DSS and IGI DigiCAM 22 airborne digital frame cameras.
The bodies from medium-format (6 x 4.5 cm or 6 x 6 cm) Contax, Hasselblad or Rollei cameras are used as the basis of these units. These 16 or 22 Megapixel digital backs have also been used in multiple in a tilted configuration in the Digital Modular Camera (DMC) of DiMAC Systems where up to four of these backs may be utilized to acquire the individual colour images that will be used to form the final composite large-format frame image. Even then, this image is only some 80 Megapixels in size.

The same limitations regarding the format size of digital cameras apply in most professional photography. However film cameras using still larger format sizes - e.g. 4 x 5 inches (10 x 12.5 cm) - are in widespread use for studio and landscape photography. To convert these cameras to digital operation, various digital backs have been developed in which the focal plane is scanned using a tri-linear array to collect separate red, green and blue (RGB) images that can be processed and merged to form colour frame images. Probably the best known of these digital scan backs are the products from Better Light in the U.S.A. and Phase One in Denmark. For example, the PowerPhase FX+ digital back from Phase One uses a Kodak Tri-linear array with 10,500 pixels, each 8µm in size. The size of the final frame image is 10,500 x 12,600 pixels = 132 Megapixels, while the file size of the RGB colour image is 380 Megapixels. Obviously the use of a digital back employing a linear array that is scanning the area of a frame over a substantial period of time is inappropriate to an airborne platform with its rapid forward motion.

For museum work, where very large maps, tapestries, paintings and documents need to be photographed for record and research purposes and for the recording of landscapes, still larger formats are required. For these applications, the Italian company, ***Metis Systems*** based in Rome, has devised its Digital Macro Camera (DMC), see Figure 3(a). This is a purpose-built camera rather than a digital back fitted to the body of an existing camera. It utilizes a tri-linear array (from Sony), which is first scanned over the lowest part of the focal plane amounting to one-third of the final image. After which, the array is then moved up using a precise mechanical transport mechanism and motor to scan successively the remaining parts of the focal plane, see Figure 3(b). Basically the scanning pattern across the focal plane is similar to

Figure 3a: The Digital Macro Camera (DMC) 1015/C used for the high-resolution digital imaging of large objects such as maps and tapestries - based on dynamic scanning of the camera's focal plane. (Source: Metis Systems)

that used in high-precision photogrammetric film scanners such as the Z/I Imaging SCAI. The drives and electronics for the X and Y scan mechanism are from Kigamo GmbH in Germany. The total size of image produced by the DMC camera is 31,250 x 38,125 pixels = 1.19 Gigapixels. The final RGB file is 3.4 Gigapixels in size. Once again, the use of this type of camera is limited to the capture of images of static objects from a single fixed position. It cannot be used from an airborne platform having a rapid movement over the ground. More details of this camera can be obtained from the Metis Web site: http://www.metis-group.com/.

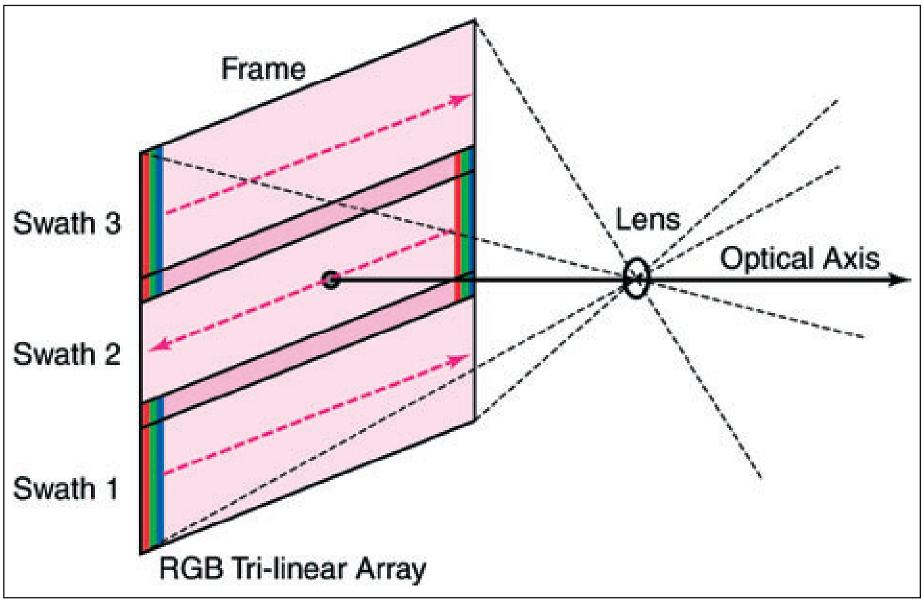

Figure 3b: Systematic scanning of the focal plane of the Metis DMC camera using a Sony tri-linear array to produce a Gigapixel frame image. (Drawn by Mike Shand)

Rotating Line Scanners

Panoramic photography, especially of landscapes and buildings, has long been popular both with amateur and professional photographers. Until recently, this has been carried out using special cameras based on the use of 35mm or 120-sized roll film. Now, however, a new generation of rotating line scanners has been developed for the acquisition of panoramic images in digital form - with the highest resolution images reaching Gigapixel size. An example is the EyeScan M3 digital panoramic scanner which has been developed jointly by the German Aerospace Center (DLR) and the Kamera System Technik (KST) company based in Dresden, see Figure 4(a).

The scanning action involves the rotation of the line scanner imager on a high-precision turntable around the vertical axis passing through the lens of the imager to give a 360° panoramic image. The rotation speed of the turntable is controlled precisely using a motor equipped with a suitable gearing system under computer control. The scanned digital image is recorded continuously in colour using a Kodak Tri-linear CCD array, 10,200 pixels in length - that is set in the vertical direction. When used in conjunction with a long-focus (f = 100mm) narrow-angle lens, the resulting digital panoramic frame image is 10,200 x 89,700 pixels = 914,940 Megapixels in size, i.e. just under one Gigapixel in size. Given the 3 RGB channels of the Tri-linear array, this produces an image file of 2.75 Gigabytes (at 8 bits per pixel) or 5.5 Gigapixels (with 16 bits per colour channel). Since it takes 10 minutes to complete the recording of a complete 360° scan, once again, the use of this scanner is restricted to the imaging of static objects from a fixed position. More details can be obtained from the KST company's Web site: www.kst-dresden.de/.

The basic geometry of the frame image produced by this rotating line scanner is very similar to that of an airborne panoramic frame camera - albeit with the distinction that that a full 360° rotation of the lens is achieved with this new type of imager instead of the 180° maximum angular coverage of the airborne panoramic camera, see Figure 4(b). There has been a strong interest by photogrammetrists in this EyeScan imager and in the similar scanners produced by the Spheron VR (PanoCam) and Dr. Clauss (Karline) companies in Germany and the Seitz (Roundshot) company from Switzerland. However all of these latter examples generate much smaller-sized images since they use shorter CCD linear arrays that are either 3,600 or 5,300 pixels in length.

This interest by the photogrammetric community has been concentrated on terrestrial applications such as architectural photogrammetry; in particular, the execution of precision surveys of building exteriors and interiors for urban modelling. This development has already resulted in two specialist ISPRS workshops on panoramic imagers being held in Dresden (in March 2004) and in Berlin (in February 2005).

Summary & Analysis

From the account set out above, it is obvious that several different approaches have been devised by the amateur and professional photographic communities to obtain Gigapixel frame images. The first approach of using a large-format film camera to acquire the images

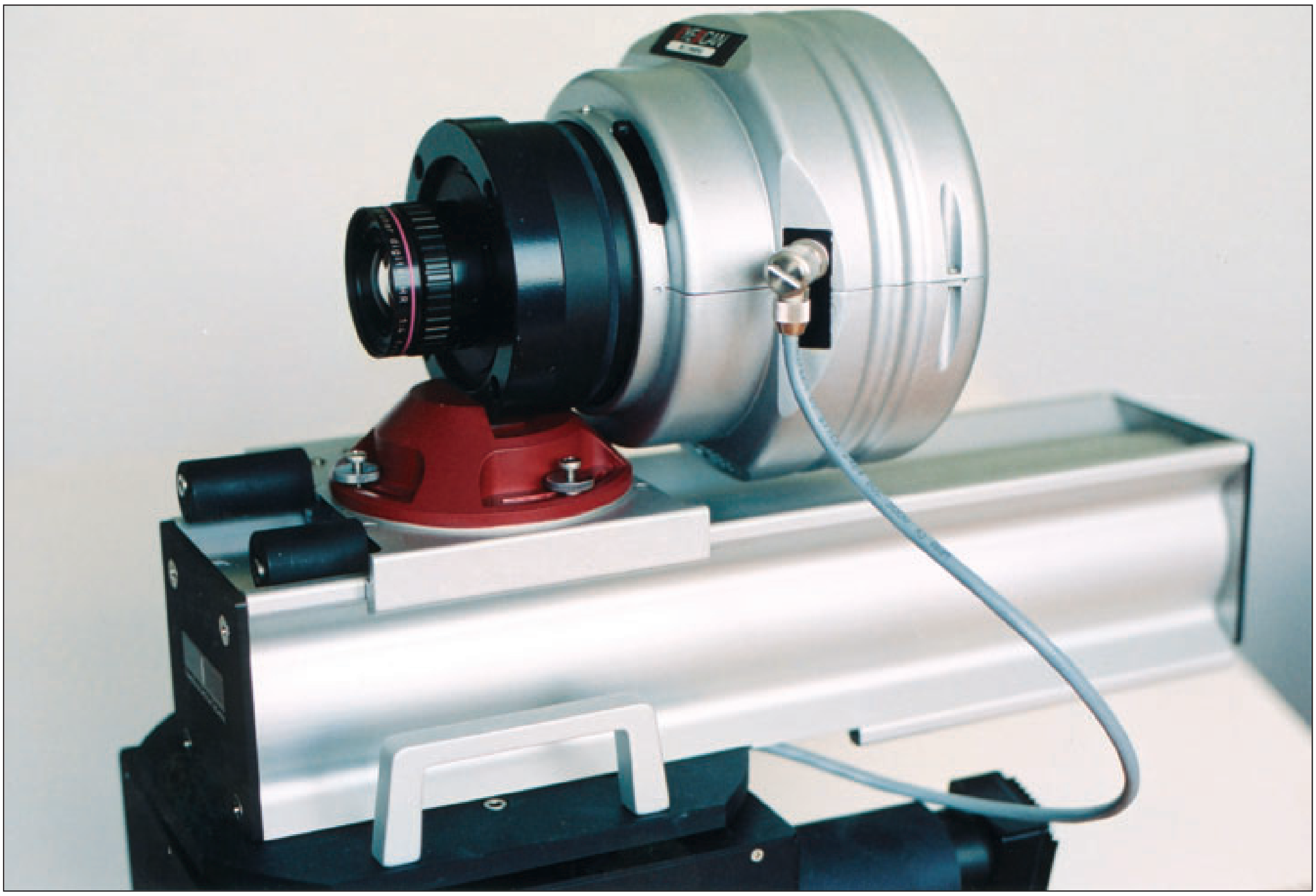

Figure 4a: The KST EYESCAN M3 Metric rotating line scanner sitting on its mount and the high-precision turntable that is used to rotate the imager during the acquisition of its digital image data. (Source: Kamera & System Technik GmbH)

and then digitizing the negative film is the same as that followed by many current users of standard-format (23 x 23 cm) aerial film cameras - with the bonus that the format size is doubled. However many years have elapsed since large-format aerial film cameras were last manufactured. Furthermore, without doubt, the trend is towards cameras that will allow direct capture of airborne digital image data.

However the main drawback with digital frame cameras at the present time is the relatively small size of current CCD area arrays with the need to have multiple cameras and sub-images that need to be processed to form the final image. Even then, the final image will only 80 to 100 Megapixels in size.

As for the other three solutions that produce digital images directly, the first of these alternative solutions involves the generation of multiple overlapping images from different pointings of a camera from a single station to produce each image over a period of time. This solution is not relevant to imaging from a moving airborne platform. The need to process and merge several hundred images is a further disadvantage. Similarly the second alternative solution of generating frame images by scanning across the focal plane of the camera using linear arrays is also inappropriate to a situation involving a moving airborne platform. Though, of course, both techniques might be appropriate to terrestrial photogrammetry, provided the subject being imaged is static over a period of time.

Much the same remarks can be made about the applications of the third alternative solution - that of the rotating line scanner generating fully panoramic images. All of which leads one to look elsewhere for technologies and solutions that might be useful for the direct acquisition of large-format frame images in digital form for aerial photogrammetric and remote sensing purposes. This will be explored in Part II of this article which looks at the exciting developments in this particular subject area that are currently taking place in scientific astronomy.

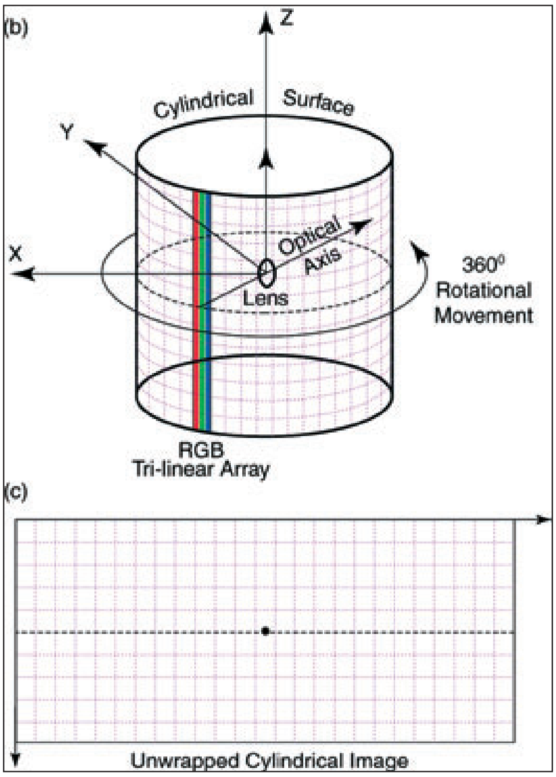

Figure 4b: The 360° scanning action of the lens and the tri-linear array that is used to produce an image on a cylindrical surface using a panoramic camera. (Drawn by Mike Shand)

Figure 4c: The cylindrical image data that has been collected by the panoramic camera can be unwrapped onto a plain surface. (Drawn by Mike Shand)

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