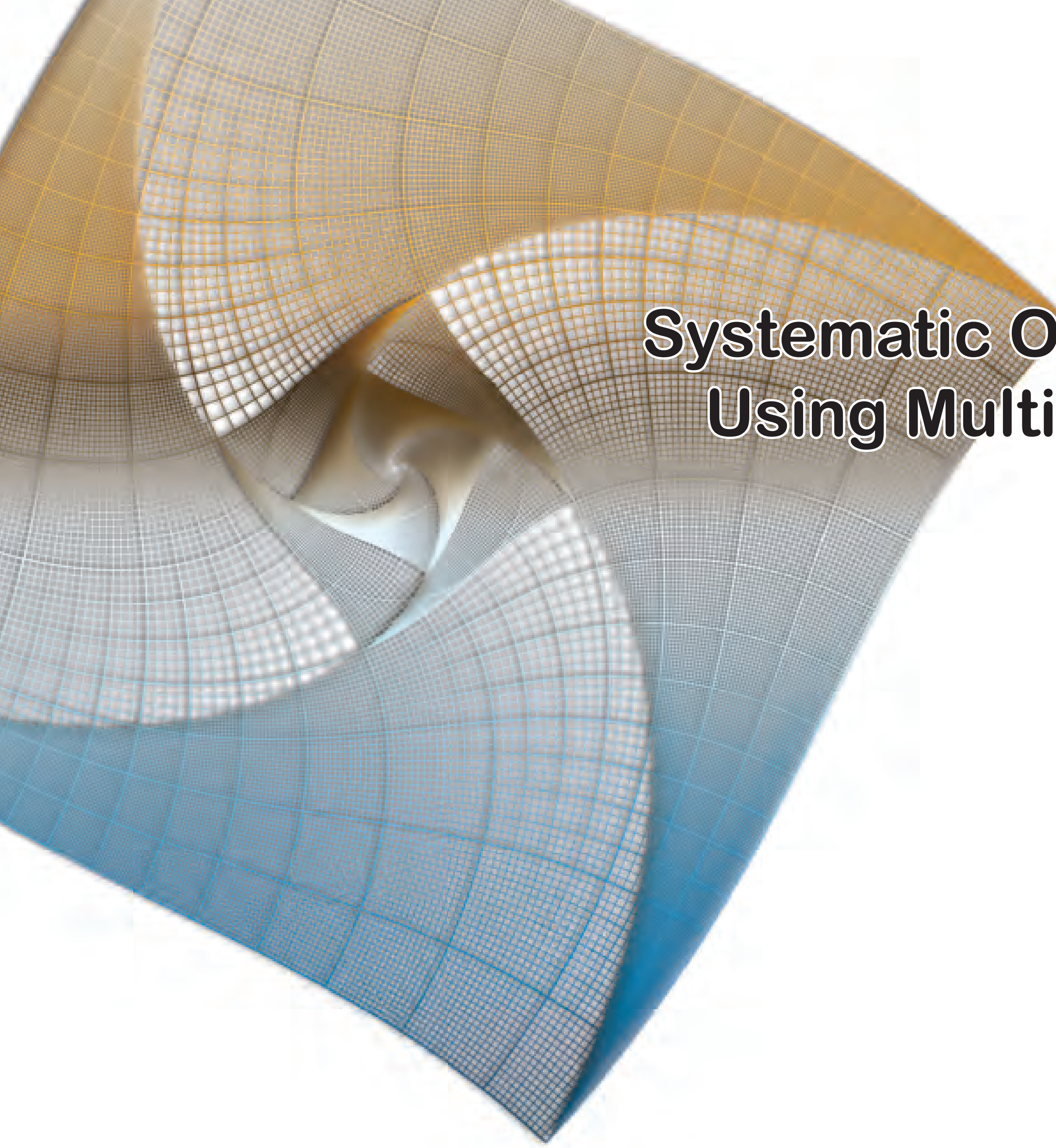

Systematic Oblique Ae Using Multiple Digita

At the present time, oblique aerial photography enjoys a much higher profile world-wide than it has done for many years. This is due partly to the activities of the Pictometry company in the United States and its numerous licensees and competitors who operate multiple oblique cameras world-wide. These companies are currently acquiring enormous numbers of oblique aerial images in a systematic manner using digital cameras, mainly over urban areas in more highly developed countries. However, many other airborne digital frame camera systems based on oblique pointing cameras have also come into use for mapping, reconnaissance and surveillance applications. This article reviews and highlights the technologies that have been developed recently to acquire multiple digital aerial oblique photographs.

Digital Aerial Camera Systems

With the advent of airborne digital frame camera systems, it is apparent that a major limitation is the size of the CCD and CMOS area arrays that are currently available for use in such systems. This has led to the widespread use of digital aerial photographic systems featuring multiple arrays, multiple lenses or multiple cameras in order to provide the ground coverage and the image format sizes that are required for mapping, reconnaissance and surveillance purposes. In many cases, though not all, it has also led to the adoption of oblique imaging configurations that are similar to those that were used widely in the period prior to World War-II (WW-II). These configurations include:

(i) ***fans*** of digital cameras exposing oblique photography to achieve greater cross-track coverage, often for reconnaissance purposes;

(ii) groups of digital cameras set in a regular ***block configuration*** that increase the overall ground area that can be covered from a single exposure station, typically for mapping or surveillance applications; and

(iii) combinations of near-vertical (nadir) and oblique pointing cameras such as the distinctive five-camera ***"Maltese Cross"*** arrangement that is being used for visualization and interpretative purposes by Pictometry and its licencees and competitors.

Fan Configurations

Fans of multiple oblique cameras have been popular for many years to provide the widest possible swath over the ground in the cross-track direction. For example, the series of Zeiss KS-153 reconnaissance film

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cameras have been used extensively by NATO air forces in both its three-lens (Tri-lens 80) form and five-lens (Penta-lens 53) form [Figure 1] to give the required wide cross-track coverage.

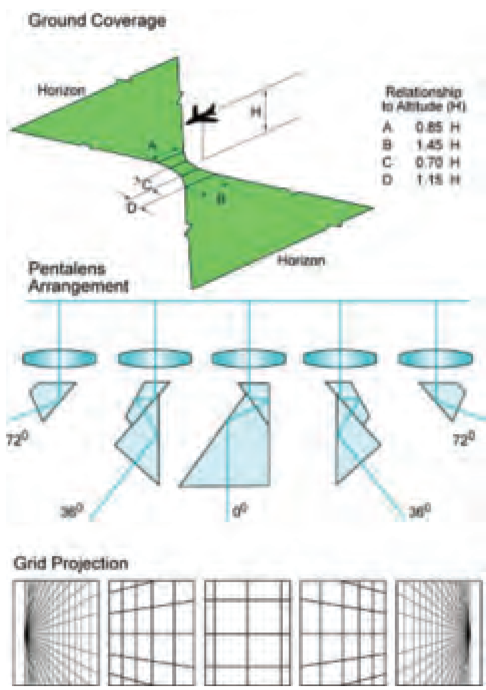

Figure 1. Diagram of the Zeiss KS-153 reconnaissance camera in its Penta-lens 53 form, providing a fan of five photos in the cross-track direction.

Twin Cameras

Turning next to their modern digital equivalents, quite a number of twin camera systems have come on to market recently from European suppliers, based on the use of medium-format digital cameras. They include the DiMAC Wide from DiMAC Systems in Belgium; the Dual-DigiCAM system from IGI in Germany [Figure 2]; and the RolleiMetric (now Trimble) AIC x2, also from Germany. All three of these twin camera units have a rather similar specification, with each individual camera having digital backs that produce images of 7.2k x 5.4k = 39 megapixels in size. Their camera shutters are synchronized to operate simultaneously to obtain the two oblique photos on either side of the flight line. After the rectification and the stitching together of the two rectified images, the final merged (near-vertical) image is 10.5k x 7.2k = 75 megapixels in size.

Figure 2. The IGI Dual-DigiCAM system featuring twin oblique pointing digital cameras mounted on a gyro-stabilized platform.

Triple Cameras

A modern example of a three-camera airborne digital imaging system is the DLR-3k system [Figure 3] that has been developed by the German Space Agency (DLR) for traffic studies. This system comprises three Canon EOS small-format digital frame cameras that are placed together on an adjustable mount in a similar configuration (providing one vertical and two oblique photos) to that of the Tri-Metrogon film camera systems that were used extensively during WW-II. An IGI AEROcontrol GPS/IMU system is used for the continuous measurement of the platform's position and attitude values. The IGI company has itself brought out a similar system which it calls its Triple-DigiCAM system. This employs three of the company's DigiCAM medium-format digital cameras instead of the small-format cameras that are being used in the DLR-3k system.

Figure 3. The DLR-3k three-camera system makes use of a fan of three Canon EOS small-format digital cameras with one firing vertically and two obliquely to provide wide cross-track coverage.

Multiple Cameras

Going further up the scale in terms of the number of lenses and CCD area arrays that can be used to provide still wider cross-track coverage using a fan configuration are the family of novel digital camera systems that have been built by the Russian NPO KSI organization. These multiple-lens airborne digital cameras utilize multiple small-format CCD area arrays in combination with four, six or eight lenses that point obliquely to both sides of the flight line to provide the required very wide coverage of the ground. In the case of the four-lens camera solution, two pairs of twin lenses are used, pointing obliquely in opposite directions across the flight line [Figure 4(a)].

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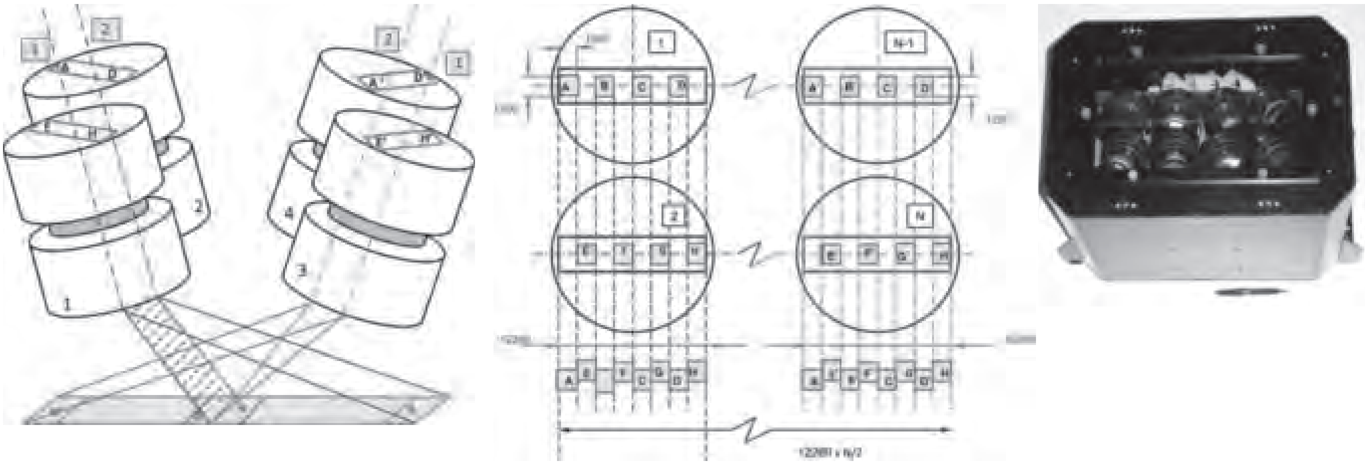

Figure 4. (l-r) (a) Diagram of the four-lens digital camera of NPO KSI, showing the two pairs of twin lenses pointing obliquely in opposite directions; and (b) the corresponding arrangement of the CCD area arrays for the four lenses. (c) The eight-lens NPO KSI camera is equipped with 32 CCD area arrays to provide ultra-wide coverage cross-track.

In the focal plane of each of the four lenses, there are four CCD area arrays. These are spaced so that the images acquired from the two sets of four arrays from one pair of lenses mesh together to form a rectangular image of the ground with its longer side in the cross-track direction [Figure 4(b)]. The images from the other pair of lenses and their sets of arrays abut on to the images from the first set of images to provide continuous wide cross-track coverage of the terrain. With a four-lens camera of this type designed to be operated from low altitudes, this arrangement provides frame images of 12,200 pixels wide in the cross-track direction. With the six-lens model based on a similar configuration – which is usually flown from a medium altitude – the cross-track coverage is 27,000 pixels wide. Using an eight-lens camera configuration, which is normally deployed from a high altitude, the ground coverage is 49,000 pixels wide [Figure 4(c)].

Stepping Frame Cameras

Another approach to the provision of wide cross-track coverage of the ground using a fan of obliquely-taken airborne digital photographs is the use of ***stepping frame cameras***. This involves the exposure of a sequence of oblique photographs at a very rapid rate in the cross-track direction using a single frame camera or a pair of such cameras placed on a rotating mount [Figure 5]. This approach has been adopted by the Recon-Optical company in the U.S.A., which is now owned, since July 2008, by the Goodrich Corporation. The company's CA-261 digital stepping frame camera can be equipped with either f = 12 inch (30 cm) or 18 inch (45 cm) lenses. This camera has been used for some years on both F-14 and F-16 reconnaissance aircraft. The newer CA-270 and CA-295 models have a dual-band capability with the simultaneous operation of (i) a camera operating in the visible/near infra-red (VNIR) part of the spectrum which produces a 5k x 5k pixel image; and (ii) a second camera operating in the medium-wave infra-red (MWIR) part of the spectrum that generates an image of 2k x 2k pixels in size. A rather similar type of twin digital stepping frame camera is the VisionMap A3 model from Israel [Figure 6]. This generates twin 11 megapixel panchromatic photos side-by-side during its cross-track scan.

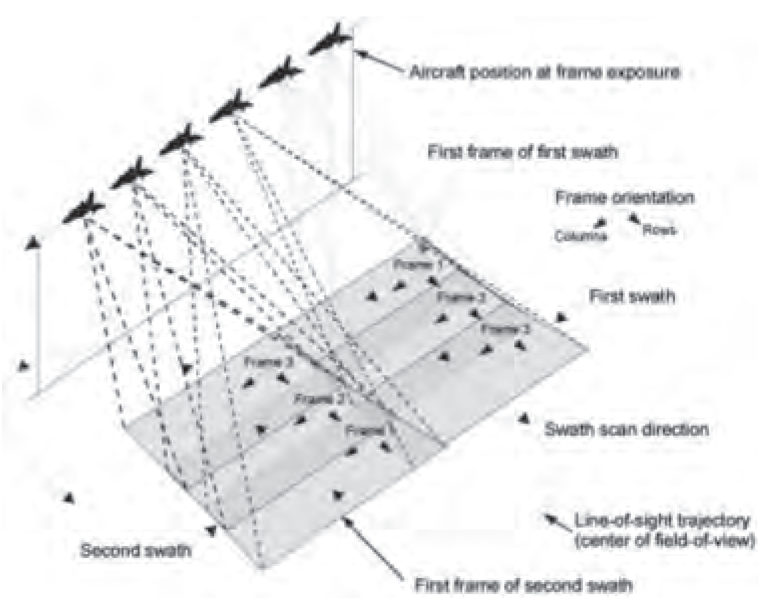

Figure 5. Diagram showing the principle of operation of a stepping frame camera.

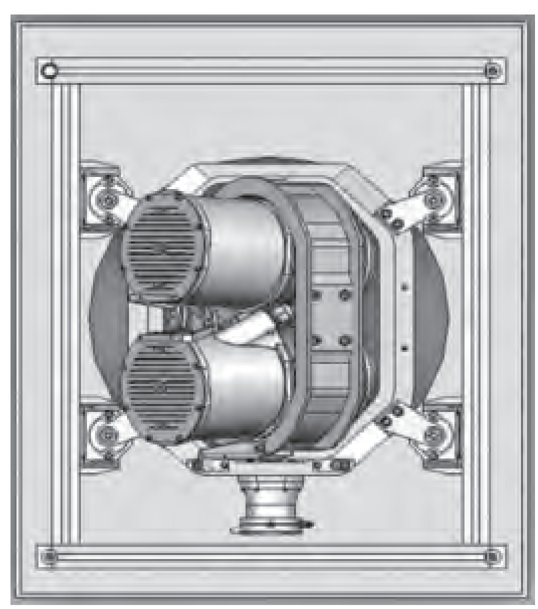

Figure 6. The VisionMap A3 twin stepping frame camera.

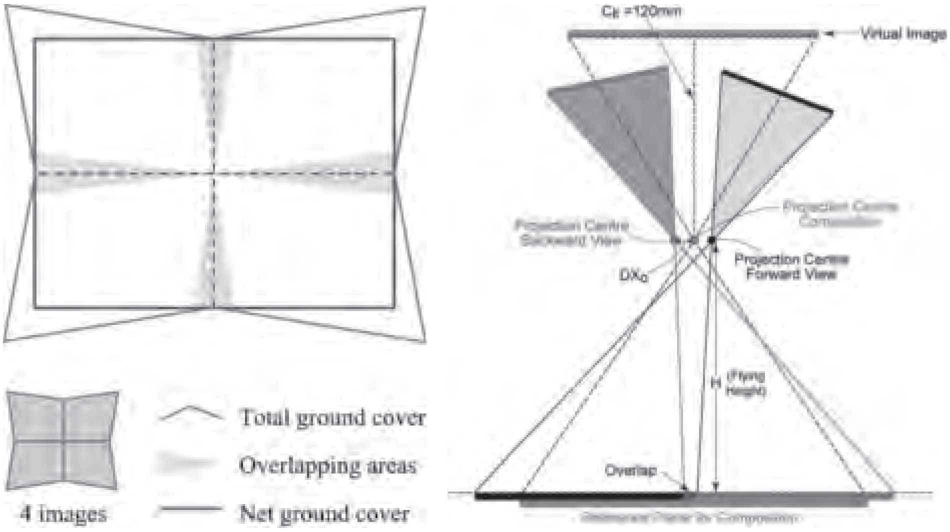

Figure 7. (a) Diagram showing the geometric arrangement, overlaps and ground coverage of a group or block of four oblique pointing cameras.
(b) Cross-section showing the relationship of the oblique pointing cameras that acquire the original tilted photographs and the final rectified "near-vertical" composite image.

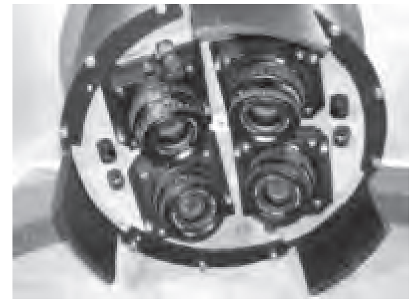

Figure 8. The Rolleimetric AIC x4 system, showing the four oblique pointing AIC medium-format digital cameras.

Block Configurations

The use of a group of four or six oblique pointing cameras, arranged in a regular block configuration [Figure 7(a)] instead of a fan, is now quite widespread for the acquisition of digital aerial photography for mapping and surveillance applications. The resulting photos are then rectified and stitched together to produce a single "near-vertical" composite image in a square or rectangular format that is delivered to users. This final composite image gives the required coverage of the ground from a single exposure station in a large format size – as required for mapping or surveillance purposes. In this large format and with this geometry, the composite photo can readily be utilized with existing digital photogrammetric workstations (DPWs) and software packages that are designed for use with any type of frame photography.

Four Camera Systems

It is interesting to note that the geometric arrangement of the Zeiss four-coupled film cameras from the 1930s is now being replicated with modern digital cameras. In the case of the Z/I (now Intergraph) DMC system that was introduced at the ISPRS Congress held in Amsterdam in 2000, four medium-format digital cameras, each with a 7k x 4k CCD area array, were coupled together in the same oblique pointing configuration. All four images overlap slightly along two of their edges. The four tilted panchromatic images are then rectified post-flight using tie points located in these overlap areas. The resulting rectified images are then merged to form rectangular large-format frame panchromatic images that, in the case of the DMC, are 13.5k x 8k = 108 megapixels in size. The final composite panchromatic image can then be colorized to form color (RGB) or false-color (VIS + NIR) images using the image data from four additional small-format (2k x 3k) multi-spectral cameras that are all pointing in parallel in the near-vertical (nadir) direction and do not need to be rectified in the manner of the larger format pan images. Over 80 of these DMC large-format digital cameras have been supplied at the time of writing this article.

A similar geometrical arrangement using four oblique pointing medium-format digital cameras has been adopted with the RolleiMetric and IGI camera systems that have been introduced to the market recently. The RolleiMetric AIC x4 system (Figure 8) uses four Rollei AIC cameras, each equipped with Phase One digital backs that utilize the 39 megapixel CCD area arrays manufactured by Kodak. The IGI Quattro-DigiCAM system also uses four digital cameras with a similar format size that are manufactured by Hasselblad, the final composite image being 145 megapixels in size. Both the RolleiMetric and IGI systems use mosaic filters and Bayer interpolation to generate the final images in colour, thus removing the need for the additional four small-format cameras that are employed for this purpose in the DMC.

Six Camera Systems

In the U.S.A., several six-coupled airborne digital camera systems have come into operational use recently. An example is the so-called "six-pack" system (Figure 9) that has been devised and built by the Space Systems Division of the ITT Corporation in cooperation with CenTauri Solutions for the purposes of persistent surveillance over large areas. These systems can be mounted on manned or unmanned airborne platforms that are capable of long duration flights with near real-time transmission of the images to ground base stations where the analysis and assessment of the images can be undertaken. The ITT system employs six small-format cameras sourced from Geospatial Systems

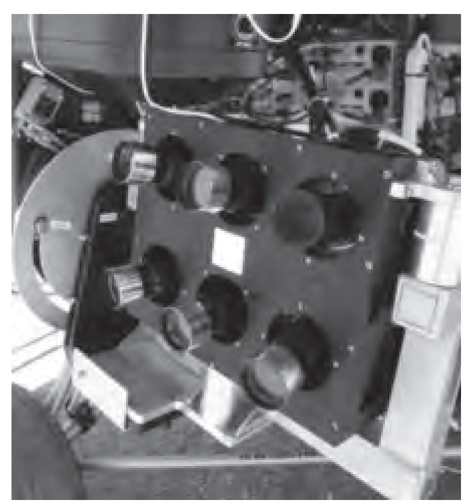

Figure 9. Showing the oblique pointing cameras of the ITT "six-pack" camera system on its rotatable gimbal mount.

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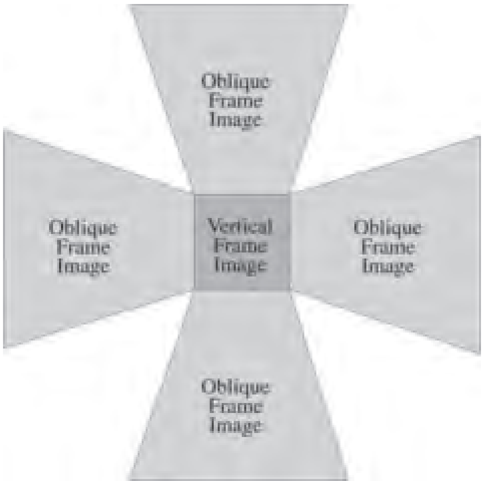

Figure 10. Diagram showing the distinctive "Maltese Cross" ground coverage of a five-camera system producing a single vertical photo and four oblique photos.

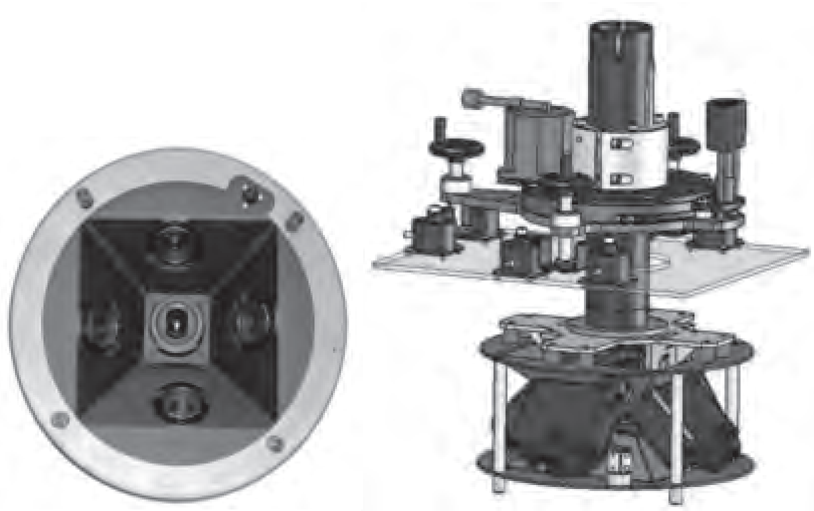

Figure 12. (a) The cylindrical camera unit of the Track'Air MIDAS system showing the lenses of the five Canon EOS small-format digital cameras; and (b) a CAD drawing that shows the arrangement of the five cameras and their levelling mount.

with each camera generating an image of 11 megapixels in size. The six individual cameras all point obliquely outwards from a central direction, the "six-pack" system being mounted on a rigid frame that can itself be tilted as a whole under motor control to point continuously at a specific area on the ground. Such systems are designed to be scaleable – either using medium-format cameras instead of small-format cameras or using much larger numbers of cameras. News items in the press and on the Web suggest that up to 24 cameras can be accommodated in such a system, which will be capable of producing images up to 864 megapixels in size.

"Maltese Cross" Configurations

This type of system comprises a single "near-vertical" (nadir) pointing camera and four oblique pointing cameras. Two of the oblique cameras point in opposite directions cross –track, while the remaining pair of oblique cameras point in opposite directions along-track. The resulting ground coverage of the five cameras takes the form of a "Maltese Cross" [Figure 10]. An early example of this particular combination of vertical and oblique photos was that of the Fairchild T-3A five-lens film camera system [Figure 11]. Thirty of these T-3A camera systems were built by Fairchild during the 1930s. They were used extensively by the U.S. Geological Survey and the U.S. Army Corps of Engineers for mapping applications using both graphical radial triangulation and stereo-plotting instruments (Talley, 1938). Each T-3A system comprised one vertical and four oblique cameras equipped with synchronized shutters that were accommodated within a single housing with five separate film magazines.

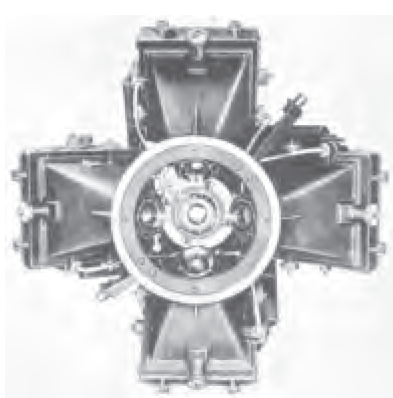

Figure 11. A Fairchild T-3A camera, showing its five-camera arrangement with one vertical and four obliquely pointing cameras.

With the digital five-camera systems that are being used by Pictometry and its licensees and competitors, the emphasis is rather different. Instead of being designed principally for mapping operations, the emphasis is placed on the perceived advantages of having multiple oblique views of urban areas at fairly high vertical angles. In particular, this type of photography is aimed at the provision of information about the characteristics of buildings and other structures that are difficult to obtain with classical near-vertical photos. It is also claimed that the interpretation of the resulting highly oblique imagery is more easily carried out by non-professional users of these photos. This has led to their widespread adoption by the emergency (police, fire, ambulance) services, especially in the U.S.A.

Pictometry has not released details of its system to the author. However, the Track'Air company, which is based in Oldenzaal in the Netherlands, is an independent supplier of these five-camera systems. It has released details of its MIDAS system, which will therefore be taken as an example of this type of system. The five small-format cameras that are used in the MIDAS system are all Canon EOS-1 Ds Mk I or Mk II models producing individual frame images that are either 16.7 or 21 megapixels in size respectively [Figure 12(a)]. The five cameras are mounted on a specially-built frame [Figure 12(b)], that can either be operated within the aircraft using a standard camera port or it can be operated externally under the aircraft, protected by a suitable fairing. The MIDAS system also uses the well-known Applanix POS/AV GPS/IMU unit to carry out the measurement of the position and attitude of the platform at the time of the simultaneous exposure of the set of five photos.

Another European supplier of these five-camera systems is IGI with its Penta-DigiCAM system. This employs a similar geometric arrangement to that of the MIDAS system, but utilizes its own medium-format DigiCAM digital cameras instead of the small-format Canon cameras that are used in the MIDAS. DiMAC Systems is another supplier that is also building a similar system based on medium-format cameras that is called DiMAC Oblique. It will comprise six cameras -- two paired cameras (like the DiMAC Wide twin-camera unit) that, when merged, will produce a single vertical image; and four cameras that will acquire the oblique images – two pointing in opposite directions cross-track and the remaining two in opposite directions along-track.

Besides these systems that employ five (or six) cameras to capture the required combination of vertical and oblique imagery, other systems have been developed recently that can capture similar five photo coverage, but using fewer than five cameras for the task. An

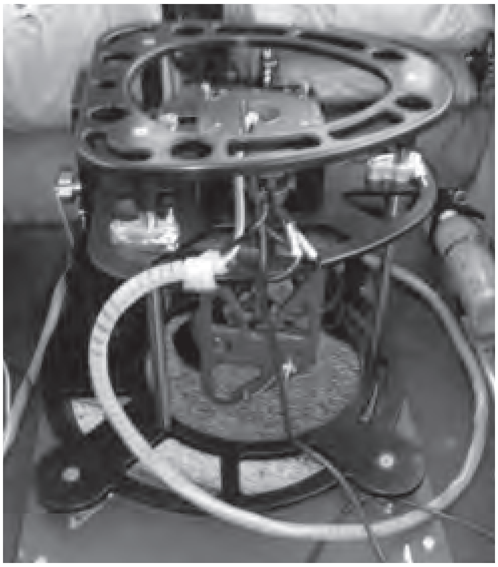

Figure 13. The Azicam on its rotating mount allows four oblique photos to be taken in rapid succession at positions 90° apart in azimuth.

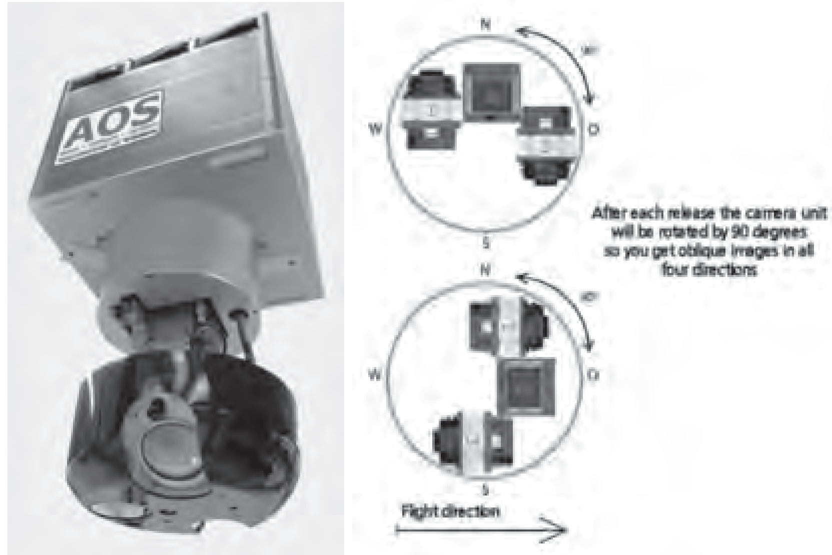

Figure 14. (a) The Rolleimetric AOS system with its three AIC medium-format cameras; and (b) a diagram showing the rotation of the three-camera unit by 90° in azimuth to allow the acquisition of the oblique photos in four directions.

example of such a system is the Azicam, which has been developed by the Geotechnologies consultancy at Bath Spa University on behalf of the GetMapping company in the U.K. This employs a single medium-format digital frame camera placed on a rotating mount to acquire four oblique photos in rapid succession at angles of 90° in azimuth to one another [Figure 13]. The fifth (vertical) photo is provided from the company's existing vertical aerial photography that covers most of the U.K.

Yet another system that utilizes a reduced number of cameras to acquire the five photos of the "Maltese Cross" coverage of the ground is the Aero Oblique System (AOS) that has been built recently by RolleiMetric for Alpha Luftbild, a German air survey company. The AOS system comprises three Rollei AIC medium-format digital camera units, each of which is equipped with a 39 Megapixel digital back. The shutters of the three cameras are synchronized to capture simultaneously the vertical image and the two oblique images pointing in opposite directions cross-track [Figure 14(a)]. The complete three-camera unit can then be rotated rapidly in azimuth by 90° to obtain the second pair of oblique images pointing in the along-track direction [Figure 14(b)]. The complete three-camera unit can be lowered down through the camera port in the aircraft floor to operate externally under the aircraft. The camera unit can then be retracted inside the aircraft when it is not in operation and during take-off and landing. The exposed images are stored on industrial PCs that can accommodate up to 3,500 individual images.

Conclusion

The use of multiple oblique cameras overcomes many of the present limitations in the size of the CCD and CMOS area arrays that can be used in airborne digital frame cameras. As a result, numerous digital oblique imaging systems using multiple small-format or medium-format cameras have been and are being designed and built for use for both manned and unmanned airborne platforms.

1. In the defense and homeland security sector, the use of scaleable systems featuring multiple oblique cameras to provide the area coverage required for "persistent surveillance" is a notable trend. Besides, the traditional requirement for wide angular coverage to allow for a large swath of the ground to be imaged at a high ground resolution during a single flight for the purposes of reconnaissance and geospatial intelligence gathering is also being implemented using fans of digital frame cameras pointing obliquely in the cross-track direction.
2. In the civilian domain, the use of multiple oblique digital cameras to generate the large-format frame imagery needed for photogrammetric mapping purposes is also a feature of the current scene. At the same time, it is extremely interesting to observe the revival or re-birth of the distinctive configuration of the old Fairchild T-3A film-based five-camera systems dating from the 1930s. This is now being employed in the modern multiple digital camera systems that are being used extensively for the acquisition of high-angle oblique frame images for visualization and interpretative purposes and as a vital component in the construction of detailed and realistic 3D city models.

References

Talley, B.B., 1938. Multiple lens aerial cameras, Chapter IV in Aerial and Terrestrial Photogrammetry: 91-116, Pitman Publishing Corporation, New York & Chicago.

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