ABOUT FRAME VERSUS "PUSH-BROOM" AERIAL CAMERAS

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ABSTRACT

When presenting digital large format aerial cameras to the interested community of photogrammetrists, one is confronted with a multitude of questions that specifically address a comparison between the basic imaging principles used with frame cameras as well as with cinematically sensing line scanning approaches. We review our insights in how these technologies differ and how the differences may affect the practice of photogrammetry. In a first segment of this report, we simply describe the technologies. In a second segment we summarize the most frequently asked questions and present our responses. Our position is defined by our need to explain the value of frame cameras in light of the existence of the alternative push-broom approach. We believe that fame imaging is the better tool for the photogrammetry application.

PART A: TWO COMPETING TECHNOLOGIES

1. MAJOR LARGE FORMAT AERIAL IMAGING TECHNOLOGIES: FRAMING AND PUSH-BROOMING

The major two technologies for aerial large format digital imaging are (a) the frame imaging approach as implemented in the Microsoft-UltraCam and the Intergraph-DMC, and (b) the linear array technology used in satellite remote sensing and transferred by Leica into an aerial system in their ADS-40. Recent product announcements by other vendors also implement a linear array principle in systems by Wehrli and Associates in cooperation with Geosystems, Ukraine, (DAS-1) and by Jena Optronik (JAS-1). This linear array technology has come to be called "Push-Broom Sensing".

The large format framing cameras are "stitching" a large format image from individually collected smaller image segments or tiles, with a sophisticated technology to ensure a geometrically accurate and seamless single large format image.

An alternative to this "single image" framing approach is the use of single or multiple middle-format cameras. Obviously, 4 middle-format cameras could take 4 images simultaneously and the resulting 4 images can be input into a photogrammetry process without the creation of an intermediate "virtual" single larger format image. At this time, this has only been applicable in the context of aerial laser scanning to "paint" the point clouds, producing 2-dimensional ortho-photos. The future will have to show whether the use of individual small middle format tiles that do not form a rigid internal geometry can compete with the large format stitched framing cameras. One such approach is that by DiMAC (Belgium).

Some confusion exists about the relative merits of push-brooming versus framing. We seek to review the differences. These will of course address the data structures, the quality of radiometry, pixel size, operational factors, stereo imaging, color as well as the most important topic of photogrammetric imaging: geometric accuracy.

2. DATA STRUCTURES

2.1 Patchwork Data Sets versus Pixel Carpets

Frame Imaging is compatible with current film-based workflows because it insets into current procedures an analog of the scanned film image. The traditional "image block" remains the basic input into photogrammetric procedures. Image interior geometry, calibration, stereo model formation etc. all remain identical to traditional softcopy approaches based on scanned film. Recall that the image bock consists of image strips which in turn are formed from overlapping centrally perspective images. Defenders of pushbroom technology call this data structure "patchwork".

"Push-brooming" produces one large file per linear array and flight line. The image "strip" is therefore a collection of perhaps 6 or 7 files, one for each of 4 color channels, plus 2 or 3 panchromatic strips for stereo work. This concept is at times denoted as “pixel carpet”. The strip image concept is not compatible with photogrammetric tradition. The image itself does not encode any geometric information, but is entirely defined by the motion of the platform. The central perspective is only applicable in the cross track direction, whereas the along track direction is an orthogonal projection. Therefore a separate workflow is needed for photogrammetric processing of data from “push-brooming” sensors.

2.2 Processing Push-Broom Data in Existing Software Systems

Since frame images have been the basis for photogrammetry for such a long time, push-broom data must get reorganized to become compatible with existing software systems. However, this transformation of push-broom data will only approximate a centrally perspective geometry. Stereo workstations are able to handle blocks of separate color images, and it is into this data format that the push-broom data need to get converted. The typical output of an Arial Triangulation obtained from a block of frame images must be replaced by additional GPS and IMU measurements taken as the push-broom sensor operates, using an integrated sensor orientation.

2.3 Operating with a Few Very Large Pixel Carpets versus Many Separate Color Image Frames

Color frame images is with a typical file size of 0.25 to 0.5 Gbytes. These need to be loaded from disks and presented to a human operator in color, and in the relevant pairing for stereo observations. The notion of multiple pixel carpets, each at perhaps 50 Gbytes, requires a segmentation of that “carpet” into tiles, much along the lines of the native framing structure.

Digital “push-brooming” image files will be at a size of 120 Gbytes for a strip of 100 km length, with 20 cm resolution and 16 bits. This needs to be related to the case of multiple separate frame entities with 0.25 GBytes files. We need to consider that clever data management always breaks up large data sets into segments for storage and retrieval, and the framing camera does this naturally.

2.4 Interacting with Large Data Sets

There exists the concept of the “Virtual Seamlessness” as a software function that uses a triangulated block of images and presents this to the stereo operator without any work or visible transition when going from one to the next stereo model as the interactive work processes data across a larger ground area. This approach invalidates any differences between “patchwork data” and “pixel carpets”.

One may also consider the ability to process imagery in parallel. This may call for the idea of smaller independent frames to be preferable over the pixel carpets

2.5 Describing Information Content

The entire number of pixels covering a project area remains the same for framing and push-brooming, provided one talks about identical ground resolution and overlap strategies. Fewer push-brooming files must be larger in size than the greater number of smaller framing files.

3. PHOTO INTERPRETATION

Practitioners of photogrammetry have long been trained to interpret frame images, for the longest time without the use of color. Color has become an interpretation key in recent years. Interpretation also heavily relies on a stereo view of the terrain.

Therefore common photogrammetric digital workstations support stereo viewing and the concept of “virtual seamlessness”. In addition, one can switch between stereo images or single images without interrupt. This makes it possible to roam seamlessly through an entire project area.

One may conclude that “interpretation” is not affected by the technology of image creation. Rather, it will be by the quality of viewing software, the quality of details in the data, color and the stereo view.

4. PIXEL SIZE, IMAGING SCALE AND THE EFFECT OF FORWARD MOTION COMPENSATION

The linear array technology of “push-brooming” in use today employs a single linear array per color band and collects photons while the pixels “dwell” over a specific terrain location. The dwell time is a function of the forward motion of the camera platform and the size of the pixel. At a platform velocity of 7 cm per millisecond and a pixel size of 14 cm, the dwell time will be 2 milliseconds. In current implementations of push-brooming, there is no option of maintaining a desired dwell time and at the same time achieving a desired pixel size. Instead, the pixel size is a mathematical function of the dwell time. Control over the pixel size independent form the dwell time would require some form of forward motion compensation FMC. In current push-broom implementations, such control via FMC is not feasible.

By contrast, there is total independence between the pixel size and the exposure time in framing technology because the exposure time is set separately and the forward motion of the platform during the extended exposure period is being compensated by what is denoted as “Time-delayed integration TDI”.

At reasonable signal-to-noise values, an exposure time of 2 milliseconds may be desirable if there is good light. At that exposure and at a flying velocity of 75 m per second (= 270 km/h), push-brooming will create a pixel size of 15 cm.

Occasionally one may get presented with a push-broom image at a pixel size of 5 cm or so. It is to be noted that such a pixel size would require that the platform flew at 144 km/h or 40 m per second and that the dwell time be reduced to 1.25 millisecond s (= 800 MHz readout, the highest possible rate). One will have to examine the radiometric quality of the resulting imagery and consider the operational validity of a slow aircraft speed and short exposure (=dwell) time. Practically, 2 msec may already represent a very short exposure (dwell) time for certain color bands, and planes flying at 40 m per second are certainly outside the norm. Therefore certain “push-brooming” owners state that they cannot achieve smaller than 20 cm pixels (See the PASCO-website for ADS-40/UC-D at http://www.pasco.co.jp/global/english/solutions/measuring_technologies/index.html#03.

The push-broom technology is being used for resolutions at 20 cm pixels over large areas, typically to produce ortho photo coverage. By contrast, the framing camera is being used at large scales with pixel sizes of up to 5 cm or even 3 cm pixels. That limits the applicability of the “push-brooming” to small-scale work. A 20 cm pixel size is analogous to a film scale at 1:10,000 scanned with 20 μm pixels. It has been shown exhaustively that a 20 µm pixel size from film will capture all the information contained in film. Scales larger than 1:10,000 will not be feasible in a routine manner with “push-brooming”. At a scale of 1:2,000 one will have to use a frame camera and a pixel size of 4 cm.

One should also note that with the digital sensors and the no-cost per image concept, the market may develop a growing appetite for larger scales and smaller pixels. In urban areas, 8 cm and 4 cm pixels may well become a new standard. These pixel sizes cannot easily be covered with the current push-brooming technology.

5. STEREO IMAGING AND STEREO MEASUREMENTS

The micro-geometry of a stereo image pair must be very rigid and accurate so that no false parallaxes are being observed. In urban settings, where 3-dimensional information is of greatest interest, or in flood plain measurements, the demands for geometric accuracy are highest. At issue is in this application the geometric position of each pixel in a world coordinate system, and differences in that position between two independently collected images to within a sub-pixel level. One will have to carefully analyze the geometric micro-accuracy of pairs of images from framing cameras and push-broom sensors to determine that it is sufficient for high precision work.

An additional consideration is viewing comfort using color. In a desirable stereo model one is viewing a pair of color images. Not all push-broom solutions are producing a color pair within a single flight line, but instead create the color data only from a nadir look.

6. REDUNDANCY

Framing cameras can image an object point as often as the overlap permits. Thus an object point can be on 10 images along a single image strip if the overlap is chosen at 90%. If the sidelap is at 60 % the object point will be on 20 images. Note that the redundancy can be chosen by the user at will, simply by adjustment of the image trigger intervals. That interval is limited only by data transfer rates. The UltraCam offers a 1 second image repeat rate.

The overlaps in the 3-line “push-brooming” are fixed to 67% and each object point is on 3 images only (forward-downward-backward).

Color values are observed in a push-broom sensor typically once per object point, and typically not in a stereo mode. By contrast, a framing camera produces multiple color observations, one per image taken: thus in an 80/60 overlap scenario, 20 color values get observed and so-called “Incidence Angle Signature” can get developed for certain objects. Recent push-broom innovations have increased the color collection to two, still far less than framing produces.

The redundancy option is important in the new and emerging full-automation of the workflow, in combination with new applications such as urban 3-dimensional models of the terrain and its vertical objects. Automation will affect the costs of projects, and a non-automated workflow may become obsolete very soon.

7. GEOMETRIC ACCURACY BY MEANS OF AERIAL-TRIANGULATION VERSUS RELIANCE ON GPS/IMU MEASUREMENTS

The "push-brooming" produces raw imagery that has no internal photogrammetric accuracy; instead the pixel carpet is a mere collection of cross track image rows with a geometry defined by the position and attitude of the sensor. Therefore the geometric accuracy must be obtained by direct geo-positioning using a GPS/IMU combination. In fact it is often suggested that the direct observation of the exterior orientation of the sensor is entirely sufficient for photogrammetry. This accuracy is defined by the capabilities of the GPS and DGPS-data and the constellation of GOPS satellites in view. This can be particularly compromised in height and has a limit in current routine operational settings of perhaps ± 20 cm in each image. The stereo-application will need to employ the differences between two images. Some work has been done to perform an aerial triangulation for strip-type imagery to achieve a better relative accuracy fr stereo work than what the direct measurements from GS/IMU will be able to provide.

By contrast, frame images provide high geometric accuracy. The inner orientation and central perspective are the result of a laboratory calibration. The "patchwork" of images in a block benefits from strong overlaps that can take advantage of redundancy to define systematic residual image deformations. While integrated G/IMU measurements may be helpful in processing framing images, they are not required. In fact, they will only serve as "approximate values" in a precision aerial triangulation and will help in the automation of that triangulation and the reduction in the number of ground control points. The image stability is measured by means of the concept of the "Sigma-naught σ_0", and values in the range of ± 1µm are being achieved with the UltraCam sensors.

We have shown elsewhere in this text that the AT-based accuracies do reach values of typically ± 0.5 pixel (± 3 cm?). Additionally, the AT can be performed fully automatically if taking advantage of the new redundancy options.

There is no σ_0 in the "push-brooming" technology.

There remains the argument that push-brooming, by virtue of its dependence on GPS/IMU measurements, has no need for ground control points. First, concerns about datum transformation issues and concern for accuracy checks will call for ground control of some kind. Second, an AT can be based on so-called "kinematic" flight management, thus on DGPS-observations just as integrated GPS/IMU-geo-positioning is using. The DGPS/IMU-observations can be input into the AT in lieu of ground control points. One could go even a step further an leave out the IMU-data. A kinematic flight management system, for example CCNS-4 by IGI has demonstrated that it is sufficient to produce cm-range accuracies without any ground control points; in fact, each image produces one ground control point in the form of its exposure station.

The AT-based accuracy is more stable, higher and better suited for stereo measurements and vector collection.

8. COLOR SENSING

A framing concept images each terrain point in color onto each image, at the overlap that has been chosen by the user. In contrast, the push-brooming sensor only obtains one that many color observations for each object point as there are linear arrays. Typically this has been 1, and very recently has been increased to 2.

A single color observation in a nadir look, as is typical in push-brooming, will not produce the required photo texture on each vertical wall of buildings for urban 3-dimensional models.

Color radiometry is an important issue. Since color is obtained by blocking (filtering) the undesired portions of the electro-magnetic spectrum, there is a requirement for a longer exposure time than is being needed in a panchromatic exposure. This factor further highlights the limitations in "dwell-time" and pixel size to achieve good radiometric performance.

One therefore will often see push-broom imagery that has a smaller radiometric range than a framing image will exhibit. To improve radiometric ranges, push-broom sensor have been seen to collect color channels with larger pixel sizes than panchromatic channels.

9. DIRECTLY OBSERVED COLOR VERSUS COLOR BY PAN-SHARPENING

Push-brooming observes color directly at the resolution of the image product. However, each color channel is collected in a separate linear array, and the arrays for the color channels need to be physically very close to one another so to avid a mis-registration due to micro-motions of the sensor. The mis-registrations between color channels obtained in red-green-blue and near infrared have been notorious, simply because those linear arrays had not been placed in physical proximity of one another.

The spatial resolution of the “push-brooming” color sensor is limited because of the need to achieve good radiometry. At a dwell time of 4 msec, the pixels will be at 30 cm, given customary aircraft speed.

Frame cameras typically collect each color channel by a separate area array CCD. The result of an image trigger is with 5-channels: panchromatic, red, green, blue, near infrared. However, the color channels are generated at a pixel size that is smaller than the panchromatic pixels. In the UltraCam, the size differs by a factor of 3. The argument is that high geometric resolution information is in “texture”, in lines and points, but not in color. Color is understood to be a property of “areas”.

Frame cameras obtain color images by combining the intensity information from the panchromatic channel with the fur color channels. Because of the inherent geometric rigidity of each frame image, the co-registration of the individual color channels and with the panchromatic channel can be achieved at very high accuracies. In the case of the UltraCam this has been shown to be within ± 1 µm. The combination of panchromatic and color channels is denoted as “pan-sharpening” or fusion”.

The argument has been made that color by pan-sharpening from frame sensors is inferior to the direct observation of color in push-broom sensors. However, this argument ignores the full complexity of color sensing with (a) radiometric range, (b) color registration, (c) color in every trigger, (d) pixel size and (e) the applications. A relevant comparison would not be by theoretical argument, but by comparing actual images (Figure 1)

ADS40, GSD = 20 cm UltraCam D, GSD = 20 cm UltraCamD, GSD = 8 cm

Figure 1
A rare example for comparing a push-broom image with frame image (Courtesy PASCO-Japan, owner of 3 push-brooming sensors and 6 UltraCams)

In fact, the pan-sharpening method has a rich tradition and is well known from remote sensing applications in scenarios where imaging is based in push-brooming, such as in IKONOS-, Spot-, Quickbird- and other satellite images.

Studies of pan-sharpened versus full resolution color did not show any performance compromise due to pan-sharpening. The analysis was based on edge sharpness measures, on stereo matching and on and use image classification, and in all cases, there was no difference found between a pan-sharpened image and the full color image (see Perko, 2004).

10. PAN-SHARPENING AND REMOTE SENSING

There is at times concern that resampling will change the color measurements. This would only be avoided if the resampling were performed by the “nearest neighbor” method. In both push-brooming and framing, the original color values are available as collected, and color values are also available after the images have gone through radiometric and geometric processing. The option exists to perform remote sensing analyses with those original values.

However, win a comparison between push-brooming and framing, one may ask the question about the value of “redundancy” for remote sensing as offered by framing. Resampled color values in the process of pan-sharpening contrast do support an incidence angle signature from looking at an object from many different angles, for example 5 angles if an 80% overlap is being flown. And in any kind of classification, one will always also make use of the object’s texture. And this in turn is being defined by the pixel size: the smaller the pixel, the more quality can be expected for the texture.

The comparison of pan-sharpened color from framing cameras versus direct color values from push-brooming has not been studied sufficiently to make any conclusive statements.

11. SINGLE LENS FOR “PUSH-BROOMING” VERSUS MULTIPLE LENSES FOR FRAME CAMERAS

The current leading push-broom aerial camera, the Leica ADS-40, uses a single lens to cover the entire swath width. Through this one lens all colors and panchromatic strips get collected. In other push-broom implementations, for example in the DAS-1 by Wehrli and Associates, there may be up to three lenses in the flight direction collecting data onto three red-green-blue linear arrays, where one lens is directed forward, one to the nadir, one backwards, and each object point on the ground gets imaged three times in full color.

By contrast, current large format framing cameras use multiple lenses with multiple area CCDs to cover a large field of view. For the frame cameras to succeed in the photogrammetric applications, the separate optical paths must be merged by software into a single “virtual” large format image.

The single lens system of a push-broom camera has advantages of simplicity, and disadvantages of complexity. The need to expose perhaps as many as10 linear CCDs in the single focal plane requires a high quality lens system covering a large field of view. The advantage of a single-lens-simplicity needs to get related to the fact that each linear array is at a separate geometric location, and therefore the color and panchromatic values are only collected at the same time for the given object point if they are split via a dichroitic prism. R-G-B and NIR are typically not collected at the same time. Imagine now that an unexpected motion occurs: the color pixels of one ground point will be at different locations, and the superposition of those color pixels will not be using any inherent geometric stability of the image since there is none. Geometric stability is essentially only based on the GPS/IMU observations. It should therefore not surprise that the DAS-1 employs 3 lenses, one each for the three geometric locations of the tri-linear CCDs.

In the framing solution the geometry of each image tile is rigid, a consequence of the simultaneity of image capture, and the assembly of the multiple lenses and tiles is rigid as well. Additionally, the UltraCam-design offers a geometric reference in the form of a “master lens”, and this supports the accurate and seamless assembly of all tiles into one single image. It is also of relevance to note that each optical field-of-view of the component lenses is exactly identical.

Using multiple lenses can have the advantage that the optical system gets less “stressed” if segments get collected separately from separate fields-of-view, as is the case in the Intergraph DMC.

So generally there does not seem to be a theoretical argument in favor on one or the other approach, but instead one will have to assess the specific technical implementation and its performance for the photogrammetric application.

12. DEFECTS IN LINEAR ARRAY CCDS FOR “PUSH-BROOMING” VERSUS AREA ARRAY CCDs FOR FRAMING CAMERAS

The highest-quality area array CCDs are being considered for use in framing cameras. Those arrays have perhaps as many as 50 “compromised” pixels in a totals of 11 million or more. One typically corrects these 50 gray values per image by means of a 2-dimensional interpolation from the surrounding unaffected pixels. The result is that defective pixels in area array CCDs have not been considered an image quality issue.

In many of these defects, the CCD-element is not “dead” but has a smaller “well” – that means that it is already full and saturated when neighboring elements still have capacity left to accept more photons.

Therefore one can correct these defects by an individual calibration of each CCD element as a function of its sensitivity.

Linear arrays generally do not have such ‘dead pixels”. If they did, then an entire strip of data would be missing, all along each and every flight line. And the interpolation to correct this defect would have to rely solely on pixels to the left ad right, not on neighboring pixels along the flight line.

Once one starts addressing the “missing pixel” factor of area arrays, one needs to point out that a linear array push-brooming approach also will exhibit missing pixels, but for an entirely different reason: a sudden uncompensated sensor motion may occur and in the process the line-CCD may move rapidly enough over the terrain so that entire objects may disappear or, inversely, may get duplicated.

Let us also consider another issue, namely “redundancy”. In the framing approach as implemented today, 5 channels of data get collected simultaneously, namely panchromatic, red, green, blue and near-infrared. Those 5 channels get processed into a pan-sharpened red-green-blue and a false-color green-red-infrared image. If one pixel at one location were interpolated from its neighbors, then in all likelihood, that pixel in all the other channel would be observed directly. From the point of view of the photogrammetric application, the interpolated single compromised pixel will become entirely irrelevant.

Redundancy also results from image overlaps, and we should recall that these are free of cost. . If any individual pixel in one color channel were compromised, there will be “n” other pixels of that same terrain point from uncompromised pixels, with “n” being the number of overlapping data points. That value “n” can easily reach 20, considering a 90% forward overlap and 60% sidelap. 20 input pixels, should one be compromised.

13. SHUTTER-FREE “PUSH-BROOMING” VERSUS FRAMING CAMERAS WITH 8 SHUTTERS

Shutters make it possible to control the exposure time. Therefore shutters provide the user benefit of producing small pixels with fast-flying airplanes but at high radiometric range due to exposure control. Shutters therefore are a valuable component in digital aerial imaging. Shutters are mechanical parts with a limited life span, and therefore are a source of camera failure. It s therefore very important to design the frame camera in such away that shutter failure can easily be diagnosed before it becomes effective and that it can be remedied in the field, preferably preventatively.

Push-broom sensors do not use a shutter since the open optical system will collect light at all times and read out the collected electric charges. Therefore no shutter failure can obstruct a push-broom sensor. However, this comes fro the price of a lack of control over exposure time for a given pixel size.

14. UNIFORMITY OF IMAGE QUALITY

Intuitively one may think that the single-lens push-broom sensor will produce a more homogeneous result than an 8-lens framing camera operating with tiles that need to get stitched. However, this concern against a framing solution would only be true if one would be unable to post-process the collected framing tiles into a seamless virtual image. Such post-processing has become a routine capability, is based on complex laboratory calibrations and use of overlaps in the image tiles, and the “uniformity” concern no longer applies.

The image quality of push-brooming technology is affected by the fact that each image line is collected separately. Imagine that sudden micro-motions occur in the sensor that cannot be perfectly compensated by the stabilized sensor mount. In those cases pixels my “smear” across an object point so that the same geometric location appears on more than one pixel. Inversely, two sequential image lines might entirely miss a specific point on the ground.

15. GEOMETRIC ACCURACY OF MAPPING PRODUCTS

15.1 Push-Broom

From a conceptual point-of-view, geometric accuracy of push-brooming is defined by the integrated GPS/IMU measurements. This can be augmented by an aerial triangulation that models the continuous flight path and changes in attitude in linear or curvilinear segments. For applications requiring a high vertical accuracy, as is the case for Digital Terrain Modeling, such refinement via an aerial triangulation is required. The idea of computing the sensor position and attitude by means of recti- or curvilinear segments is not well-established photogrammetric practice. As a result there is only a poor experimental base of knowledge about achievable accuracies. The redundancy within an image configuration is not strong – a ground point typically is being imaged 3 times within a flight line, representing a 67% forward overlap.

Yotsamat et al. (2002) have analyzed data from PASCO Corporation's ADS-40 and report an accuracy of ± 0.1 m to ± 0.2 m in planimetry at a GSD of 0.2 m and an RMSE of 0.02 % of height above ground level which is at least twice the error we expect from frame cameras. Zeitler and Dörstel (2002) achieve an ADS-40- accuracy of ± 0.23 pixels in X and Y and ± 0.39 pixels in Z, with a value for σ_0 at ± 2.4 µm or ± 0.2 pixel.

15.2 Frame Cameras

Framing images are analogous to scanned centrally perspective film images, and the entire heritage of photogrammetric aerial triangulation is applicable. A block of images represents separately exposed centrally perspective photos. The resulting sigma-nought value is a descriptor of the internal stability of an image block, and residuals in check points on the ground serve as an absolute measure of geometric performance.

Investigations with the UltraCam have shown that the σ_0 of AT-results is consistently better than ± 1 to 1.5 µm or 1/5 to 1/10 of a pixel. Comparing computed XYZ-coordinates of check points with values measured on the ground produces residuals in the range of less than a pixel.

15.3 Systematic Errors

There exists in photogrammetry the concern about uncompensated systematic errors in image blocks. Those may be very small, say in the range of 1 micrometer across an image, but due to the systematic nature can have a destructive effect on a projects overall accuracy. Image blocks may result in a deformed project area, as if the block was "warped". Frame cameras offer the capability of eliminating such systematic errors based simply on the use of information from within the images themselves such as overlaps and redundancies, and proper mathematical models. Changes of temperature come to mind as a primary source for un-modeled systematic geometric effects. In current digital frame imagery, the consideration of systematic errors has seen the geometric accuracy increase by 50% or more.

We are unaware of work to detect and remove systematic errors of unknown origin from push-broom imagery.

15.4 Accuracy Applicable to Ortho-Photo Production

We have seen practical accuracy considerations to cause push-broom imagery to be used mostly in ortho-photo production. The underlying terrain elevation data then do not come from stereo-matching of the push-broom data, but instead get created by aerial laser scanning. Of course, the practical reasons to limit push-broom applications to ortho-production based on laser-scanned elevation data may also be connected to the acceptable pixel sizes and to the ability to stereo-match images with the given radiometric ranges.

16. B/H RATIO

In push-broom sensing, as implemented in the ADS-40 or the JAS, the linear CCD arrays get placed in the focal plane in such a way that a desirable stereo-base-to-height ratio is obtained. In the implementation of the DAS-1, separate lens cones are employed for a forward and a backward look so that a fairly large B/H ration is available. B/H ratios as seen in conventional wide angle film cameras are typical for these systems, thus at about 0.6.

By contrast, frame cameras produce a B/H-value as a function of the image format. Since current frame cameras operate with rectangular formats with the short side in flight direction, the B/H values in a typical 60% forward overlap are smaller than with wide angle film, namely at 0.25. This is at times being considered a weakness of current frame technology. However, there is a mitigating factor it compensate for this weakness, namely the quality of the stereo match. Given the high radiometric range of frame imagery, the stereo matching error reduces so that a result is obtained not unlike that from a larger ration, but with a greater matching uncertainty.

Additionally, frame imaging offers flexibility in setting the forward overlap. Consider a project with an 80% forward overlap: in that case each terrain point within a flight line gets images 5 times, and images 1 and 5 combine to a stereo impression at B/H – 0.5, not that much different from traditional wide-angle film images. With a smart approach to stereo-matching, frame images not only ofer superior matching precision, but also a large B/H-ratio.

17. SPECTRAL BAND SEPARATION

Spectral-band separation is a result of the choice of filters. Which filter to use is a rather soft concept. with no basic difference between the push-brooming and the framing technologies. The ADS-40 uses interferometric narrow band filters, whereas the UltraCam uses broader overlapping volume filters. The advantage of the broader filters is that one achieves an image quality more like that from color film. Narrow band filters are sometimes requested by remote sensing-oriented users, but the resulting radiometry is more limited since such filters pass less light and would need longer exposure times; exposure time is not a parameter to be set in push-brooming. The trade-off is thus between radiometric range and pixel size.

18. THE RADIAL DISPLACEMENT

If push-broom sensing is within a vertical plane then object displacement as a function of object height is within that plane only. The so-called “radial displacement” of elevated terrain objects such as buildings or trees is in cross track direction only, and along the flight line, the image would be an orthogonal projection. This factor of radial displacement in only one direction is at times considered to be advantage.

Frame images obviously are centrally perspective and therefore have a radial displacement away from the optical center; that displacement has a component in flight direction as well as across the flight direction. Obviously then, buildings will lean radially away from the nadir and one will see all four facades if one considers overlapping images within a single flight line. This factor can be seen as a significant advantage of frame imaging.

In a “true” ortho-photo, thus an orthophotos without any radial displacement, one will have to re-project the image onto a surface model, as part of a standard true ortho-photo-production. Workflows exist to achieve this for both push-broom and frame sensor inputs.

19. STEREO VIEWING

Stereo viewing for 3D-measurments is a central photogrammetric technique. This has been developed for pairs of centrally perspective imagery. The “vertical exaggeration” of objects that extend from a reference plane is attractive to provide good “stereo acuity”, but is also a problem if it is too large for normal human viewing.
Push-brooming is only centrally perspective in one direction and an orthogonal projection in the other. The aspect angle under which vertical objects are seen is the same along the image strip and changes only in one direction, namely from left to right, thus across the fight direction. In framing stereo, the vertical objects are seen under changing aspects angles that change radially outward. In one case, namely framing, the user will therefore be able to see multiple sides of a vertical object, with push-brooming he will not.

Viewing and measuring can be separated into two functions. The viewing can be done by the human observer selecting a pair of images to view as is most comfortable, if redundancy supports a choice. Measuring is a function of setting a “floating” measuring mark on the terrain surface. That could be achieved automatically by a computed image match, with the human viewer observing the result. This may be useful in cases where the radiometric range of the images is higher than the ability of a computer monitor presenting that radiometry to the eye. The radiometric range from frame imagery is in excess of 12 bits, and achieves often 7,000 gray values, whereas a monitor may only present 250 grey values to the eye.

Finally, a human operator has two eyes and therefore can only see two color images at a time. But one may have a project with 10 or 20 images covering each terrain point. Stereo viewing will only be able to employ a non-redundant pair of color images, thereby ignoring the many additionally collected images. The computer, by contrast, can process any number of images simultaneously, as if it had an unlimited number of eyes. Stereo-viewing as a basic concept is at the verge of being replaced by the idea of “stereo-guidance” of an otherwise automated image analysis process. In that scenario, more redundancy will produce more robustness, more accuracy and more automation. The issue is then not which technology, push-broom or framing, but better image matching by better radiometry and more robustness by increased redundancy.

20. ON THE ISSUE OF RADIOMETRIC QUALITY

Radiometric quality is a result of a system’s optimization and perhaps less so a result of the underlying technology. In the end one needs to assess the number of grey values in an image. This number is affected by the choice of components, signal conditioning, analog-to-digital conversion, calibrations, signal to noise suppression, exposure time, aperture setting etc. In the UltraCam, more than 7,000 grey values get collected routinely and this represents nearly 13 bits per pixel and color band. Push-broom images have been reviewed and 8.9 bits per channel were found.

21. ON THE ISSUE OF "PRODUCTIVITY"

"Productivity" gets affected by all the parts in the entire processing chain from planning a photogrammetric project, collecting data in the air, checking the quality in the field for a need to potentially re-fly a mission or some parts, to shipping data, then going through the entire photogrammetric and cartographic processing chain until delivery of the finished digital terrain data with a quality and accuracy report. The sensor and sensor technology are but a factor in an elaborate workflow. However, push-broom and frame technologies do need different workflows resulting in somewhat different software systems and drills. In addition, one technology will be more versatile than the other and able to support many purposes as opposed to being limited to a reduced set of applications.

As a mission progresses and a day's data collections are done, the raw push-broom images are not yet useable. They need to await completion of the post-processing of the differential GPS and IMU-data so that the raw images can be "fixed". Quality assessments will not be feasible until those "fixes" have been verified.

Current frame camera technology has the advantage over push-brooming that the raw images can be directly processed in the field or even in the air to asses their quality and to make decisions about re-flights.

Another difference is the need to maintain a traditional workflow for scanned film while the new technologies get accepted. Here the advantage for fame imaging is obvious since its workflows are identical to those for film imagery. This is not the case for push-broom inputs.

Frame technology offers an avenue to better automation due to more redundancy. Once the AT is automated and free of ground control points, say by means of kinematic flight management or integrated GPS/IMU direct geo-positioning, the number of images in a block becomes largely irrelevant for the production throughput. Instead it is the ground area which defines the project costs. Once a workflow is set up for this case, advantages will accrue in the creation of Digital Terrain Models, ortho-photos, 3D urban building models and such. One can hope that with this workflow, the appetite for the instant-gratification from laser-point clouds no longer remains applicable.

Of course, aerially collected push-broom imagery can be treated as any satellite images are: most photogrammetric software packages have the capability to accept strip images from space (Quickbird, Ikonos, Spot etc.), and as a result, the aerial strip imagery is also accepted by such software. However, the motion of aerial platforms requires a different level of model-complexity than the stable path of a satellite, so that the use of satellite-oriented software for aerially collected strip images seems lime a "band-aid" approach to photogrammetry.

Note finally that productivity is massively affected by the type of airplane platform and its velocity are concerned. Being able to fly fast clearly is desirable and may reduce the exposure to weather. Flying a lighter plane may safe fuel and costs. Push-broom sensors want the plane to fly slowly to achieve the smallest possible pixel size. Frame cameras do not need a slow plane.

22. REFERENCES

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PART B: FREQUENTLY ASKED QUESTIONS ABOUT THE ULTRACAM LARGE FORMAT DIGITAL AERIAL CAMERA SYSTEM

1. BACKGROUND

Aerial mapping film photography is based on the concept of “scale”. This in turn determines accuracies, or example in elevation measurements, typically assuming that this accuracy can be 1 part in 10,000 of the flying height.

Aerial digital imaging is based on the concept of “pixel size” or “ground sample distance GSD”. The two concepts are related via the size of the scan pixel in a photogrammetric scanner. It can be shown that a digital camera pixel is equivalent or superior to a film pixel scanned at 20 μm pixel size, or even at smaller pixel sizes of 15 μm, 10 μm or 5 μm. This has rather conclusively been shown in a doctoral thesis by R. Perko and published in the most recent ISPRS congress (see the paper available from the Website Download C.6, Paper by Perko et al., 2004).

For example, photographic capture of film imagery at scales 1:5,000 can be considered equivalent to digital images taken with a ground sampling distance GSD of 10 cm. The film scale 1:12,000 is then equivalent to a GSD of 24 cm.

There is ample evidence that geometric mapping accuracies better than ± 1 pixel are being achieved with digital aerial cameras. This statement replaces the film-base statement about the 1 part in 10,000 vertical accuracy.

When considering a transition to digital imaging, one should realize that this option is very new. Indeed, a few years ago, a fully digital photogrammetric workflow would not have been productive and competitive. However, with the continuation of the Law of Moore, the IT-infrastructure has now reached a level where a fully digital workflow under the motto of “film camera out, digital camera in” is now feasible and advantageous. Improved operational flexibility and efficiency are the benefit, and so is a cost reduction.

Cost reduction is first and most immediately achieved by the savings on consumables like film and film processing, and by savings for no longer needing to scan.

Another cost factor is that for the information technology infrastructure. Continued applicability of Moore’s rule promises that a 10:1 improvement of the cost-benefits should become feasible over the next 60 months in CPU power, storage capacity, transfer speeds. The intimidation by terabytes will disappear completely, and the peta-byte will become common a concept.

However, a more significant issue in the transition to the digital workflow is the savings potential in the reduction of manual labor to produce mapping products. A 10:1 savings should become feasible over the next 36 months, as software and imaging strategies emerge to bring to bear the full potential of the fully digital photogrammetric system.

The following questions and answers derive from a series of exchanges with customers and their concerns. Each of the questions was actually asked by a customer and these questions are collected with the answers, giving a mosaic of clarifications about the fully digital workflow, the UltraCam camera system, customer support, information technology and other subjects.

The material is organized in 6 categories which are loosely separated from one another:

- The Camera System
- Customer Support
- IT Requirements
- Commercial Issues
- Operational Questions
- Future Technologies

These questions and their answers are of course supported by material in the form of detailed papers. These are available from the web in the form of Downloads, as listed in the Attachment.

2. DIGITAL CAMERA SYSTEM

2.1 Footprint Coverage

The UltraCam-D camera has been designed to cover the same swath width as a traditional aerial film camera. This is applicable if one accepts that the GSD of the digital camera equals or surpasses the equivalent GSD of the film, obtained by scanning the film with 20 μm pixel size.

The digital camera does not produce a square image, but instead a rectangular instantaneous exposure. The effective angular coverage is 55° cross track and 37° along track (see also the technical specifications in Attachment B.9). Across track this results in a geometry identical to a traditional film camera with a format at 23 cm and a focal length at 21 cm.

At a flying height of 6,000 feet, this results in a ground coverage of each image with 1867 m by 1217 m (easily computed using the number of pixels at 11,500 x 7,500, a physical pixel size in the focal plane of 9 μm, and a focal length of 101.4 mm).

2.2 Stereo Coverage

Stereo coverage is a function of the image repeat rate. The UCD is able to achieve an image repeat rate of 1 second or better. Therefore it will be producing a 60% forward overlap at all pixel sizes a typical survey application might ever need, say even down to a GSD or pixel size of 3 cm. Given that along track, 7,500 pixels get recorded per image, a 3 cm pixel/GSD represents an along track ground distance of 225 m. A 60% forward overlap requires that an image gets repeated after 40% of the along track ground distance, namely every 90 m. At a typical air speed of 70 m per second, stereo at 60% and with a GSD of 3 cm will be achieved if the images get taken and stored every 1.3 seconds. A forward overlap of even 70% is feasible for the GSD at 3 cm, using the UC-D.

Of course, achieving this at 3 cm pixel size makes it trivial to achieve the same (a 60% forward overlap) at a GSD of 10 cm or 24 cm.

The stereo base-to-height ratio of the UCD seems at first sight inferior to that from a classical film camera. Two factors show that this may be misleading. First, stereo accuracy is not only a function of base-to-height ratio, but also of the accuracy of stereo matching; and this is superior for the digital images over film by a factor in excess of 2.

Second, the possibility of flying with higher forward overlaps at no extra costs in a film-less system produces two new advantages over film: there is the option of multi-ray matching (not stereo, but multi rays), producing improved accuracy and robustness. And finally, the higher overlaps lead to each point on the ground being covered by a stereo pair that has a high base-to-height ratio, if the extreme images covering a location on the ground are considered. For example in an 80% forward overlap, images 1 and 5 have a small overlap, but this overlap is at a high base-to-height ratio.

Automated methods and efficient roaming in interactive stereo will make it possible to work with high overlap data very efficiently.

2.3 Capture of multi sensor imagery

The UC-D produces 5 channels of data: a panchromatic image spanning the visible part of the electro-magnetic spectrum, plus the three traditional color bands red, green and blue, and also a near infrared band. A separate sensor collects each spectral band, with the optical path passing through a filter, lens assembly and a CCD array. The bands are selected as follows:

Panchromatic	390 …. 690 nm
Red	570 …. 690 nm
Green	470 …. 660 nm
Blue	390 …. 530 nm
Near infrared	670 …. 940 nm

These bands get collected in each and every image, at all times when an image gets triggered during the survey flight.

2.4 Spatial Resolution of imagery

The spatial resolution GSD of the digital images (in mm on the ground) results from the physical size of the pixel in the area array, p, at 9 μm, the focal length, f, at 101 mm and the flying height H in meters which is customer-selected. The relationship between GSD (in mm) and flying height (in m) is as follows:

GSD = p* H / f;
H = GSD * f/p

A GSD of 10 cm is achieved from a flying height of H = 1127 m.

At a flying height of 300 m above ground, the GSD reduces to 2.7 cm, a spatial resolution routinely being achieved by customers of the UC-D in special engineering and urban mapping applications, for example Meixner Consulting in Vienna (Austria).

To actually realize such pixel size in a meaningful manner requires that sufficient light is collected over an extended exposure time, say during 4 milliseconds. Since the aerial platform moves during the exposure at a velocity of perhaps 70 m per second, or 7 cm per millisecond, the GSD would not be achieved due to image motion and smear; during a 4 millisecond exposure time, this would be about 28 cm, invalidating the 10 cm requirement.

Therefore a so-called “Forward Motion Compensation FMC” is needed and implemented in the UC-D that counteracts this motion and cancels it out.

The 5 spectral channels are produced at two different spatial resolutions. The panchromatic image is created with a focal length of 10 cm, the 4 color bands are created with a focal length of 28 mm. The final color and color infrared images are produced by fusing the panchromatic and color bands into a so-called “pan-sharpened” image at the spatial resolution of the panchromatic image.

2.5 Radiometric Resolution of Imagery

The Analog-to-Digital conversion of the UC-D is at 14 bits to ensure that 12 relevant bits get collected. Typically, digital numbers (DN) will be recorded across a value range of 7,000 (13 bits).

The sensor itself responds to exposure of light in an analogue way (to be very correct we need to say that the charge produced is limited to steps of the elementary charge of electrons) and its usable dynamic range is specified to be bigger than 72dB. This correlates to the resolution of a digital system of slightly better than 12 bit. Our camera radiometric specification of 12 bit system dynamics reflects this fact.

To get true 12 bit out of a sensor one needs to keep in mind some system specifics like a necessary headroom and system noise level. As a direct consequence the resolution of an analog-to-digital converter (ADC) needs to be greater than the actual dynamic range of the sensor to avoid unnecessary limitations. That is why the UltraCam-D operates with an industry-leading 14 bit design. A 12-bit design of the A/D Converter would not produce a true 12 bit output image.

In case of the UC-D sensors, the so-called "full well capacity", i.e. the saturated response, could be in the range of 2100mV, typically to 3400mV maximum after the output charge-to-voltage converter. To be able to deal with the maximum possible value, the typical value will not fully exploit the system's dynamic margins. This fact and some minor gain influences are reflected in the "Intensity threshold" test result.
Given a noise level of less than ± 2 DN, the UC-D is able to meet the system specification of a true 12 bit dynamic range.

At times the argument is being made that a 12 μm surface area of the CCD elements is “better” than a 9 μm surface area. This is a misleading argument. Important is the dynamic range, and this is the ratio between the full well capacity and the noise, and this is not a function of the surface area of the CCD element. To ensure that this dynamic range of the sensor elements gets used in the system, a balanced electronic chain needs to be in place, and this is only feasible if there is a 14-bit A/D conversion being used, as argued above.

2. 6 Radiometric Accuracy

Level-2 images, thus the radiometrically and geometrically corrected, stitched and color registered post-processing outputs, are present in a 14 bit format. From there, level 3 images can be produced in many different formats including full resolution pan-sharpened color respectively false color infrared images in 14 bit or 8bit radiometric resolution. The operator is able to influence this conversion to 8 bit by providing automatic detection of highlight/shadow levels at settable threshold and gamma values. Consequently specific target histogram parameters are achievable by setting the processing parameters in a suitable way.

2. 7 Radiometric Consistency

Choosing the same settings for level 3 post-processing (see MR6) in each image leads to consistent results. The accuracy of digitally controlled exposure settings is the precondition to that statement. To further improve visual radiometric consistency in case of abrupt changes of scenery, an automatic matching of radiometric parameters over successive frames by evaluation of overlapping areas is being implemented for the next release of the post-processing software.

2. 8 Geometric Accuracy

The UC-D has been designed to provide an internal image geometric accuracy of equal or better than ± 2 μm. This is being achieved and assessed in various ways.

First is the fact that the camera geometric accuracy is defined by the geometric accuracy of one and only one optical "cone", the so-called master cone (please refer to the product literature for the definition of the "master cone" and the internal workings of the UC-D and the response to IR5). This geometric accuracy is being achieved and verified by means of the laboratory calibration (see a separate explanation of the calibration in Web Download C.2 and the response in MR9, and some product technical literature separately attached in Web Download E). The residuals of that calibration are in the range of less than ± 1 μm.

Then the so-called slave cone images get merged with the master cone image. This results in residuals between the slave images and the master image. These residuals are consistently well under the specified value of ± 2μm.

Finally, the color bands get fused with the panchromatic "master", and this process also results in an accuracy assessment by means of residuals, also as specified, thus under the value of ± 2 μm.

Finally, the system accuracy can be assessed by means of aerotriangulation (AT) results, expressed by the internal noise value denoted as "sigma-nought". This is also found to be better than ± 2 μm, however, depending on the type of terrain and the illumination, which affects the stereo matching used to define tie points between overlapping images, and those tie points propagate into the accuracy of the AT.

2.9 Camera Calibration

The camera calibration is of course a major element in producing a photogrammetric camera. A separate technical article published in the photogrammetric literature describes the calibration technology used for the UC-D and is separately attached with this Tender (Web Download C.4).

The geometric calibration is based on 84 images taken with the camera in a calibration laboratory. The images are taken in various positions and orientations of the camera, imaging a precisely surveyed test field. A total of 14,000 tie points and control points are then automatically selected and measured in each of the panchromatic images, and 60,000 tie points in the color bands.

The point measurements get entered into a bundle block adjustment to determine a number of geometric elements of each cone and each CCD as follows:

Lens Focal Length
Lens Principal Point
Lens Distortion Field
CCD-Shift
CCD-Rotation
CCD-Scale
CCD-Shear
CCD-Perspective Distortion

The achieved accuracy typically gets reported as:

Panchromatic:	sigma_nought ≤ ± 1 μm rms
Color:	sigma_nought ≤ ± 1.5 μm rms

Independently the radiometry is being calibrated using images of dark current (no light falling on the sensor), and of radiometric test targets (black and white, and color). These test images serve to compute the following

- Vignetting of each lens, for each setting of the aperture;
- Dark current and gain (a linear transformation of the sensed radiometric values into useful values), for each CCD;
- Dead pixel table, for each CCD
- Color transformation values, for each color band.

The radiometric calibration produces residual noise value of ± 2 DN in a 14 bit scale, converting to ± 0.15 DN in a linear conversion to 8 bits.

2.10 Camera Calibration Maintenance

The UC-D gets calibrated before delivery and installation and will then be factory recalibrated once per year. There is insufficient experience to determine at this time whether this schedule can be relaxed to 2 years.

The camera performs an internal geometry check, simply due to the internal redundancy from using the panchromatic and color image bands. Any geometric anomaly can therefore be identified automatically from the residuals of the fusion procedures for each and every collected image. A service call to Vexcel is recommended when unusual residuals are being noted.

2.11 Camera Maintenance Contracts

Available as Website Download B.1 is a camera maintenance contract and as Download B.2 a description of the Internet-based 24/7 customer support system that is currently brought into action. This has started to be used with the about 300 users of Vexcel's photogrammetric scanner product, the UltraSca5000. The more than 1000 users of the Vexcel-ISM stereo photogrammetric software system DiAP and SysImage will be brought into this system next.

The frequency of maintenance required cannot yet reliably be reported; the install base with currently 12 systems is too small and too recent to have produced conclusive solid information. The initial year of a customer's UCD-use will see the following programmatic support efforts:

- Initial training associated with the installation;
- Second training period after initial customer experiences have been accrued;
- Preventative maintenance after 6 months;
- Factory re-calibration and re-certification of the camera in Graz (Austria).

The support is offered from Graz (Austria), by Vexcel staff from the support department of the company.
The initial response to a customer support call will be based on an initial remote diagnostics to determine remotely what causes a specific problem.

The response to a call is instant, 24 hours a day and 7 days a week due to the global network of Vexcel companies, and due to mobile internet connectivity. The first step will always be a remote diagnostic effort to identify the reason for a perceived problem. The attachment in Web Download B.2 explains this in more detail.

Included in a full maintenance agreement is all labor and all parts, but not travel expenses in the form of travel tickets and lodging.

The MTBF of key parts are far in excess of what would affect a reasonable use of the camera. For example, the shutters are specified to operate for 4 million operations before a failure is likely. The shutters are the only mechanically moving parts that could typically fail from operation.

Disks and CPUs are set up so that a trained customer technician can exchange them, should there be a failure. The same applies to the cabling between sensor unit and storage and computing unit.

In terms of "service levels", the Web Download B.2 explains that the option exists to just singn up for the internet based remote diagnostic service and have each call that requires travel, parts and on-site labor be quoted and billed separately.

A three-day down time requires that Vexcel reserve a back-up system in Graz (Austria), should a problem not be resolvable within a three-day period. This system can be shipped to the Customer within a one-day period and installed within less than an hour.

2.12 Integrated production flow line

The images get collected in the air in the form of raw level-00 images, in redundant form by mirroring each image onto two disks. The entire sequence of image data levels s as follows:

Level 00	Captured raw data, stored twice on the camera
Level 0	Verified raw data, stored on the MSU or in the office.
Level-1	Radiometrically corrected data, stored temporarily in the camera or in the office.
Level-2	Geometrically corrected, stitched and registered image data, stored as a set of files which consists of the image data (native resolution of PAN, 1 channel, and COLOR, 4 channel) as well as quickviews and additional data files.

Level-3	Final output color R-G-B and false color NIR-R-G images at full geometric resolution, to be used as if they were scanned film images.

The use of the UltraMap server as an integral (but optional) element of the camera processing system accommodates the management not only of data, but also of the project work and computer processing functions. Web Download B.3 presents a description of the Server and its operations and uses. The Server is an

- Archive for large quantities of images;
- Catalog to administrate these images via meta data;
- Project management tool to launch software, administrate and review the processing of the collected images.

The interface to the Customer's in-house photogrammetric processing software is via TIFF files, much as if the digital images had been scanned film. More on the Integrated Production Flow will be presented under MR 15.

2.13 Interface with Existing Digital Photogrammetric Production Systems

Again and as stated under MR12, the level-2 and/or level-3 images will be submitted to pre-existing photogrammetric image processing software. The current install base of 12 (14 very soon) cameras is interacting with a great variety of photogrammetric software. To this software, the digital camera images are but simple aerial images as if they had come from the traditional photogrammetric scanner. The internal orientation can be skipped (or an "empty" transformation is being applied) since the output images from the camera are already aligned to the image coordinate system along rows and columns.

The image input into existing photogrammetric software is by means of standard image formats such as TIFFF and JPEG. These are compatible with most photogrammetric systems.

As a result, the Intergraph-Z/I suite of photogrammetric software is being routinely used at the Vexcel customer site at Sanborn Map Company, Colorado Springs, USA or GeoTec/NODIC of Germany. The SocetSet software is being used by a majority of customers, for example by IFMS-Germany or PASCO-Tokyo.

The Leica image dodger software is also compatible with the described standard formats TIFF and JPEG.

The import of imagery into the pre-existing software at the Customer will therefore be feasible. Other software packages also have been used at other locations, as also described under Item IR11.

2.14 Compatibility with Specific Aircraft

Experience exists with various aircraft models. Even the Cessna 206, as a typical survey aircraft, is large enough to hold the UltraCam-D. Various aircraft are being used by current UltraCam-D customers, or have been used in camera tests. The Spanish customer TASA operates with a Turbo Commander; experiences with the Cessna 404 were collected in tests with the German company, we have customers with Cessna 206 and 208, have flown with the King Air etc..

"Compatibility" issues do therefore not exist. What needs to be made certain is that the aircraft is prepared to receive the digital camera with respect to the electric power and cabling requirements. These will be reviewed in a pre-installation visit and need to get prepared under the guidance of an installation expert of Vexcel. Power consumption for the UltraCam system on board is below 35Amps @ 24V to 28Vl.

Also important is the arrangement to mount the SCU (Storage and Computing Unit) in manner that passes Civil Aeronautics Board requirements. Such requirements have been met, both in Europe and in Japan, where formal inspections by these aeronautics agencies were held, in Europe via Bildflug Fischer (Klagenfurt), and in Japan with PASCO-Tokyo.

To ease the installation Vexcel provides an aluminum SCU adapter plate including security locks.

Parts going into the aircraft:	(Weights approx.)
Sensor Unit (SU):	45 kg
Storage and Computing Unit (SCU):	65 kg
Interface Panel (IP):	5 kg
SCU Adapter Plate:	10 kg
Set of interconnecting cables	

Dimensions and angle of view preconditions will be verified based on drawings provided as part of the pre-installation review.

2.15 Duration of Flying Days

Elements of the Data Flow in the Field:
The UltraCam-data flow employs a tool for transfer of data between the aircraft and the field or home office called a “Mobile Storage Unit” (MSU). It also employs another tool called a “Mobile Server” (MS) for in-the-field-copying of image data onto large LACIE disks. The flying operation needs a minimum of MSUs defined by the number of flights per day a camera will need to make, at most. Thus if the camera fills its internal on-board storage with 2,700 images twice per day, then two MSU’s are needed.

A Customer’s Requirements, Translated in Data Quantities per Day
The requirements by a customer was stated in terms of geometric resolution at 10 cm, and 8 hour flying periods, three days in a row. At a 60% forward overlap and 20% side-lap, and assuming that mobilization from the airport to the target area is 100 km, and that each project area is square, leading to 40 km strips and 38 turns. This will result in a number of daily images to be at 5,120 covering 1550 square kilometers. This implies that the plane will land once during the day to unload the full storage system on board with its 2,700 images onto a first MSU, taking about 1 hour. Then at the end of the day, another MSU will receive the second stack of 2,700 images.

The initial MSU will be free the next noon to receive the “harvest” from the first flight of the second day, and the second MSU will receive the second harvest at the end of the flying day. This arrangement can go on in perpetuity, using just two MSU’s. Each MSU of course will serve to quickly unload data from the onboard system to free the plane for a next flight.

Across three days, a total of 15,360 images was collected this way. They all will be stored twice on large LACIE-disks for shipment to the home office, or for on-site storage for later retrieval for post processing into level 2 and level 3 images.

About the Data Flow
(a) In Flight Collection of Raw Level 00 Data
Standard operations serve to collect raw level-00 images in the air. Each triggered image consist of 13 sub-images of 11 Mega-Pixels each. Level-00 images get stored twice by “mirroring” the data on 2 disks. The number of such images to be collected is 2,700, occupying about 1.5 Terabytes.

(b) Checking the Aerial Coverage
The aerial coverage is in principle defined outside of the camera, in the flight preparation and flight management system. As the survey flight goes on, the camera operator can monitor the collected data on the graphical user interface by means of so-called “quick-looks”. These quick-looks are stored for later use. On the ground, the completed flight can be replayed via the stored quick-looks at an interval of about 0.5 seconds. If security is an issue, then a completed flight can be checked right after the mission is completed.

(c) Verification and Off-Loading of Level-0 Data from Airplane
c.1 Verification and Off-Loading onto the SCU: A “verification” run gets started on the SCU to ensure that the level-00 data are not compromised. This results in level-0 images data to be copied onto the MSU (Mobile Storage Unit). This copying process is accelerated by means of the use of multiple disks and parallel data transfer. A full SCU with 2700 images will be copied and therefore off-loaded in less than 1 hour. The SCU and the MSU now hold duplicate copies of the collected (“harvested”) image data. Since duplication of the data is now abandoned, the resulting maximum data quantity is 750 Gigabytes.

c.2 Level-2 Processing on the SCU: Optionally the collected level-00 data can be processed directly into level-2 data. For this purpose a mobile server in the form of a notebook computer and a large disk need to be attached to the SCU so that the level-2 images can be stored on the external disk. The process produces 1 image every minute. Therefore the SCU-post-processing is only advisable if the there are small numbers of images to be processed, and if a comfortable environment with electric power and no environmental stress exists. Processing is into level-2, not into level-3.

(d) Back-Up of Down-Loaded Data to Maintain Data Security
The MSU, once filled with the data harvest of a mission, can be copied onto a singular large disk. This operation may take up to 10 hours, since the sequential transfer of data fills the resulting disk. However, if the MSU received the collected data at the end of a flying day, there is time until the next day’s end, again in the afternoon, when the MSU is needed again to collect the harvest of the next day.

(e) Maintaining Redundant Copies for Data Security
It is very important to plan that at all times there are two copies of the harvested data being available. The SCU-resident version of the data should no be deleted until the MSU has been copied or a single copy will exist until the MSU-copying process is completed.

(f) Quality Control by Selective Post-Processing
Post-processing of the collected images may not occur until some later time, in cases where the survey plane is far from a post-processing capability. In that case one may want to obtain some selected images post-processed in the field. This is being supported if the user extracts some selected images, say every 100th image, from the level-0 collection.

These selected images can then be post-processed on a laptop computer in the field at a rate of perhaps 4 minutes per image. Processed image samples are then available for quality control.

The user has in this case at his disposition both the quick-looks as well as the selected fully post-processed level-2 and level-3 images.

(g) Transfer of Level-0 Data to the UltraMap System, and Post-Processing into Level-2 and Level-3 Images
The MSU or the singular disk with a coy of the level-0 data is being loaded onto the UltraMap-server (see the description of the server in Web Download B.3). This server produces a fully protected archive and catalog of the level-0 and the level-2 as well as level-3 images. The post-processing runs automatically. The throughput per image is scalable, but a throughput at 1 minute per image is the norm in a low cost 4-CPU PC-system.

The MSU or the disk copy of the MSU-content must be shipped to the Server. The Server takes on the role of the traditional photo-lab.

(h) Results of the UltraMap Process
The UltraMap-Server fills the catalog with the meta-data about the images, and fills the archive with the full resolution images, as desired by the user. Images are organized by project, block, sub-block, flight line, stereo pair and individual image.

Information about each image gets read off the image header, for example the exterior orientation as obtained during flight from the flight environment.

(i) Transition to Customer-Preferred Pre-Existing Photogrammetric Software
The customer-resident applications software, for example SocetSet or the low cost system Photomod, now can access the data-base and call up images as needed for subsequent photogrammetric processing. Images for use in SocetSet get ordered from the UltraMap-server and transferred via an Intranet (or Internet) connection.

If the Server is equipped with Vexcel's photogrammetric software (yet to get released), then processes can be run automatically under control of the COP management system.

(j) Alternatives
For post-processing in the field, the customer has options to set up a small field Office Processing Center. If a throughput of 1 minute per image is desired, then about 4 PCs are needed. However, that will not have a cataloging and archiving function.

2.16 Operational Limitations
The minimum flying height for the camera operation is not defined by the camera but by the aircraft operations. The forward motion compensation permits one to collect images at any flying height. The maximum flying height is also not an issue of the camera, but again of the aircraft operations. The disks are protected from low air pressure by airtight seals. The UC-D has been flown in un-pressurized airplanes at an altitude of 25,000 feet with no problem.

The temperatures under which the UCD has been operating have ranged from the snowy northern Norwegian mountains to the tropical heat of a South African summer. This has proven the successful meeting of temperature requirements which state that the camera should operate even at temperatures of up to 72 degrees C.

2.17 Storage Level Monitoring
The Storage and Computing Unit is a combination of 30 disks with 60 Gbytes of storage each, thus a large 1.8 Terabyte disk storage, as well as a collection of 15 computers. Therefore there exits a user interface reporting to the camera operator at any time an entire host of data on the project and on the

contents of the storage system. The total capacity of the storage system is initialized a the beginning of a survey flight at 2,750 images. Hen at each trigger and collection of an exposure, the counter counts down by one. So at any time, the user can supervise the number of images collected and how many can still get collected.

The user manual in Web Download D.1 presents an explanation of the on-bard GUI to support the camera operator to show in detail what information is being made available to the operator.

2.18 Flight Planning

The UC-D is fully compatible with leading flight management software and systems, in particular with IGI's CCNS-4 and Trackair's Xtrack. We choose to propose in this Tender the system by IGI, due to Item DR3, where it appears that the Customer is employing this system at this time. In MR21 the Customer refers to its use of an Applanix POS-AV 510 system, and that system is routinely being integrated with the Track Air flight management system. However, both the IGI and the Trackair solutions have been integrated with the UCD at customer sites, for example the IGI system at Getmapping in the UK, and the TrackAir system at AeroData in Belgium.

As seen from Web Download B.4, the IGI-CCNS-4-system fully supports a wide range of preparatory and post-flight functions in accordance with the description in MR18, while also guiding the pilot and survey crew through a chosen flight plan.

We meet this requirement by offering and integrating the IGI Win-MP software.

2.19 Aerial Triangulation

This MR addresses geometric accuracies of an aerial triangulation, however without reference to the density of ground control or the accuracy of a DGPS and IMU system, and without any reference to measurement accuracies as a function of the type of terrain.

The UC-D has repeatedly resulted in a sigma-nought of the AT of better than ± 2 μm, and at sub-pixel accuracies in height, and far better than a pixel in planimetry. Given the Customer's need to fly with GSD (pixel sizes) of 10 cm and 24 cm, the accuracies in planimetry at ± 10 cm and in height at ± 20 cm will be achieved routinely, since it would be in the range of a relaxed ± 1 pixel..

To achieve such accuracies, ground control will be used. The density of that control is a function of the overlaps used in the flight. Since cost of images is unrelated to the number of images, a higher than traditional overlap will be economical, as long as the AT-software can run largely automatically. This wll reduce the need for ground control density.

Various AT-projects have been performed with UC-D images to result in a sigma_nouhgt in x and y at ± 0.2 pixel, and in z at ± 0.7 pixel. In a technical paper for the ISPRS congress (see the Web Download), Vexcel reports a multi-ray matching accuracy at ± 0.6 pixel in z.

2.20 Aerial Triangulation – Geographic Transformation

The use of the IGI CCNS-4 includes the relevant transformation between coordinate systems (for example in the UK the transformation OSTN02 between the OSGB36 and ETRS89 systems).

2.21 Integration with DGPS/INS Systems

Several UC-D customers operate with exactly the Applanix equipment specified by the Customer, the Applanix POS-AV 5120. The integration of the camera and that DGPS/IMU system is for example implemented by AeroData, Antwerp, Belgium, PASCO-Tokyo, Sanborn Map Company of Colorado Springs, USA and others.

On the back side of the sensor unit (SU) a cabinet is provided for stable implementation of the IMU (see drawings to be provided before the installation.

2.22 Delivery

Currently, Vexcel has 10 camera systems in the manufacturing pipeline via WILD-Austria, with the first of those 10 rolling off the assembly line by November 22nd, 2004. Should a contract get awarded in response to this tender, then Vexcel will have a unit reserved for delivery under this contract, well within the specified period of 4 months from the presumed date of award, thus before March 11th, 2005 (given a contract closing date of 11 November 2004, as assumed in ITT-Section 9).

2.23 Blur Free Images

As presented in Web Download D.1 about the GUI of the onboard system of the camera, the camera operator has available a measure of light coming into the camera, and he has available a manual tool for changing the exposure time and aperture settings, during flight.

Regarding flying speed requirements, there are no practical limits, due to the electronic forward motion compensation, allowing for up to 50 pixels displacement during exposure.

At issue is the operator's ability to instantly detect blur in images due to other effects, not forward motion. This could be a malfunctioning stabilized platform. This is available on the platform itself. An effect on the images of this malfunction of the platform is not can be detected in flight by means of the on-board CPU power. Its implementation is pending.

2.24 Quality assurance of captured images

As the airplane lands, several options exist to review the images that were collected.

First is the play-back/review of the on-line quick-look images that are being computed on the fly at a resolution 1/8 of the full images. This shows flight lines, overlaps, coverage, cloud issues, aperture and exposure time settings, image brightness and color.

Second there is an option for a so-called “quick-look photogrammetry”, as a quality control step prior to full image post-processing into level-2 and level-3 format.

Third is the ability to collect a few raw images for in-the-field instant post-processing on a laptop computer, at a rate if currently about 4 minutes per image, going to level 2 and level-3 images.

2.25 Camera Lens Protection

The Sensor Unit (SU) comes with a massive rubber protection cap ready for aerial operation. To cap or uncap, it is necessary to lift the camera preferably by using a mount providing a tilt mechanism.

2.26 Field Test of the Camera System

It is not untypical to define an obligation by Vexcel to provide a camera for field tests before delivery, yet after contract. Such tests are possible since multiple a test systems exist in Graz (Austria). The customer is welcome to come to Graz and perform field tests in advance of receiving its own system. “Free of charge”, as specified by the customer, will be acceptable as “no exchange of funds”. Vexcel will carry its own expenses in supporting the field test, not however the expenses incurred by the customer.

2.27 In-Flight Quality Assurance Of Imagery

As previously presented, there exists an in-flight Graphical User Interface GUI for in-flight quality control and imaging parameter settings. This is based on quick-view images produced on the fly, using the on-board computing power residing in the SCU (15 CPUs). The functionality of this GUI is described in the Manuals as attached in Web Download C.

2.28 Sensor Capture Options

The general UltraCam design is based on a high-resolution panchromatic image and color excerpts at lower resolution. Roughly 70% of the raw data collected contributes to the panchromatic channel. Therefore at present time we do not provide the possibility to switch off color channels. As an additional benefit of that strategy, all level-2 imagery is stored in the same format and different final customer formats could be derived easily afterwards.

2.29 Flight Planning Of Existing Film Cameras

The UC-D operates with IGI CCNS-4 and Trackair flight management systems. Therefore it has become customary with existing camera users, that the film camera gets swapped out and replaced by the digital camera, and back, as a matter of routine.

In fact, this is exactly the design goal of the UltraCam-development: to be compatible with the film camera world, and therefore to operate under the motto: “film out, digital in”.

Specifically, therefore, the UC-D can be swapped against an RC-20, and even use the PAV20 or PAV30 mount in which the Leica RC20 may operate. And the connection with the pre-existing IGI CCNS-4 will be upgraded as an option to operate the UltraCam-system (see the optional quotation for this IGI upgrade).

In the same way, UCD can be integrated in a Z/I RMK TOP environment as long as the flight-management system is compatible (see list above). However, UCD is not mechanically compatible with the stabilized T-AS mount because of the diameter of the main camera. To be able to swap the UCD with the Z/I RMK TOP, the installation of a different mount will have to be considered. This is why this Tender includes the quotation of a new mount as an option.

The functionality of the IGI CCNS-4 remains fully in place when used with the UC-D camera.

2.30 Digital Camera System Technical Specifications

Technical Specifications

The technical specifications are presented as a separate Web Download B.9.

Camera Components

Parts going into the aircraft:	(Weights approx.)
Sensor Unit (SU):	45 kg
Storage and Computing Unit (SCU):	65 kg
Interface Panel (IP):	5 kg
SCU Adapter Plate:	10 kg
Set of interconnecting cables	

Parts for ground use only:

Mobile Storage Unit (MSU) for data export and saving

Power Supply Unit (PSU) powers the whole system from mains supply (wide voltage inputs for worldwide use).

Postprocessing can be carried out on the SCU, making use of its 15 PC processing power, or on a distributed system of office personal computers running under Windows operating system.

Our UltraMap Server is best suited for postprocessing and archiving of UCD images.

Digital Sensor

We make use of 13 similar area array sensors of type DALSA FTF4027M. Nine of them form a 3 x 3 matrix to produce high resolution panchromatic images, the remaining sensors produce a color frame each in the red, green, blue and near infrared band respectively.

The sensors were developed by the renowned Philips Digital Imaging Divison, now DALSA professional imaging.

The expected lifetime is that of high quality electronic components resulting in many years of error free operation. Replacement can be done easily because the sensor adjustment is done independently from the rest of the optical system. So replacement cost would be limited to the basic component costs plus cost for calibration and test flight.

Video Camera

No video camera is being used at this time, simply because the on-board computing power permits the system to compute quick looks on the fly and these serve more directly any purpose that the video camera could serve.

2.31 Project status metrics

The response to this informational request is attached in Web Download B.10.

2.32 Metadata

The image data contain several parameters in the file header (GUID, time, number, see Web Download D.4). Depending on the connected FMS additional data are collected (as a separate ASCCI text file). This file contains the Exposure Annotation Data (EAD, see attached Web Download D.3). The camera image numbers and GUIDs are also saved by TrackAir and CCNS-4 to match the final processed FMS data with the images automatically.

In addition the customer can create its own meta-data file with other parameters (format is described in attached Office Manual, Web Download D.2).

2.33 Camera mount requirements

As previously presented, the UltraCam can be operated with pre-existing mounts such as the series of PAV mounts by Leica, and the SM-series from former East German Zeiss-Jena. It does not fit into the stabilized T-AS mount by Intergraph-Z/I.

It will be the Customer’s call how to best make use of the UC-D system. To make sure that all options get covered, Vexcel is optionally quoting a stabilized mount GSM3000 by SOMAG. The specifications of that mount are provided in Web Download B.11.

2.34 Principles Of How Digital Camera Functions In The Aircraft

The operating principles of the camera in the aircraft are described in publications and the manuals, as enclosed. Permit me to specifically address the issues raised in the ITT.

Function

The camera operates with four identical lenses having all the same field-of-view, collecting 4 identical black and white (panchromatic) images. The difference between the four lenses is the place in which the CCDs are located in the focal plane. The location of the CCDs results in a partial image from each lens, since not the entire field of view is collected onto CCDs in each lens. Each partial image has holes. Note the four image planes in the four lens systems have different numbers of CCDs in each focal plane: there is one partial image from 4 CCDs in a focal plane (the “master cone”, 2 sub-images with 2 CCDs each, and one sub-image with only one CCD (the “slave cones”). This represents 9 CCDs collected four partial images. By “adding” up the four individual sub-images, one obtains a large image with a single geometry and a single perspective center.

The panchromatic image is collected separately from the color bands. Each color band (red, green, blue, near-infrared) represents a separately collected black and white image, again using identical fields-of-view. By merging the color bands, a color image is obtained. The color images are at a reduced geometric resolution vis-à-vis the panchromatic image. A higher resolution color image is obtained by fusing the panchromatic and color images; this process is called “pansharpening”.

The system thus operates with 8 lenses and 13 CCDs (9 for the panchromatic image, 4 for the color bands).

The graphic illustrations to explain the functions are presented in the Appendices (Manuals).

Data collection

Data get collected by a transfer from each CCD via the sensor electronic system including a 14 bit A/D converter, and sends the sensed data via a firewire to a dedicated CPU per CCD to a pair of disks, also per CCD.

Data Storage

Each triggered image results in 13 data sets being stored, one per CCD, and of a copy of the data sets on spare disks. In the end, the Storage and Computing Unit SCU holds two copies each of the triggered contents of the 13 CCDs on a total of 26 disks. On 26 disks, each with 60 Gbytes, one can store two copies of 2,750 images.

Light Metering

The camera sensor itself is a light meter. On the fly, the onboard CPUs compute a histogram for each CCD-frame, and it computes a quick view image. The histogram is analyzed on the fly to comment on the amount of light being collected, and the quick view images are being presented to the operator for quality control. The GUI contains a display with the collected amount of light for the operator’s review.

Drift Setting

In case the mount is drift-controlled, obviously no additional drift control is necessary in the camera itself. The drift control information coming from an FMS is simply passed to the mount by an external adapter to be flexible with different environments.

In case there is no automatic drift control of the mount via FMS, the in-flight preview provided by UCD could assist in manually control the drift angle. This works well especially at settings giving high overlaps and fast frame rates respectively.

Operator Monitor

The interactive GUI in the airplane has been described at various occasions in this Tender, and is fully explained in the attached manuals (Web Download D).

2.35 Digital Camera Management System

Again, the attached manual (Web Download D) explains the operator functions and the capabilities to plan a mission , manage the collection of the data and then manage the post-processing into level-2 and level-3 images.

Camera control

- The camera control software is basically self-checking which indicates the problems of the computer and sensor modules and automatically reacts if the problem has been solved.
- The camera can be operated by 9 soft-keys.

- The operator can prepare different flight projects
- In the air test shots can be taken to control the exposure settings.
- The recording can be executed as manual single shots, automatic sequence and triggered from an external source (FMS)
- During recording each capture is displayed in the in-flight feedback area (quick views and brightness control)
- The camera has an integrated image viewer to display and check all images on the camera
- In addition the camera has an interface to FMS for v/h and GPS information

Data Storage Control

- The captured image raw data is saved twice
- A warning is displayed if the redundancy failed or if one disk has write performance problems (in such a case the operator can also switch to back-up unit)
- The image data consistency is checked each time the system is switched-on

GPS/INS Control

- The camera can be triggered by external sources and gives a mid-exposure pulse back
- In addition it has a communication interface to receive parameters for recording (v and h) as well as exposure annotation data.
- The communication interface is compliant to TrackAir and IGI-CCNS4
- Vexcel also provides an open general communication interface (see attachment Web Download D.3)

Navigation and flight planning information

- The camera only requires the exposure parameters and some record control parameters (see attached user’s manual in Web Download D.1, Section “prepare”).
- During the recording it can receive GPS information which is stored in a flight support data file to be imported during the office processing.

2.36 Is a 9μm Pixel Size Compromised vis-à-vis a 12 μm Pixel in the CCD Array?

I summarized the statement made in response to the Tender’s 5, referring to the signal-to-noise ratio as the decisive factor, and this being specified by the chip manufacturer DALSA at 72 dB for CCDs at both pixel sizes. 12 μm pixel size is the 90’s technology, 9 μm pixel size is the current technology. Pixel sizes at 7.2 μm are going to be next, all specified at 72 dB.

2.37 Confirmation that the UC-D Corresponds to a Film Camera with 21 cm Focal Distance

The focal length at 100 mm, the image format at 103 mm and the pixel size at 9 μm need to get multiplied by the factor 2.1 to end up with the equivalent dimensions for a classical film camera with focal length 21 cm, format 23 cm and a scanner pixel size at 20 μm.

3. CUSTOMER SUPPORT

3.1 Digital Camera System Warranty

Web Download B.5 presents the Warranty statement of Vexcel, to complement the Maintenance statement in Web Download B.1. A 1-year warranty is standard for Vexcel’s camera system.

3.2 Customer Support of the Digital Camera System

The installation, training, acceptance testing are an integral part of the UC-D delivery, as quoted later. On-site support is available under an upgrade from the 1st-year warranty to a 1st-year maintenance, as quoted elsewhere.

Call-off support will be provided to the following conditions:

- Budgetary indication of necessary support two weeks in advance
- Binding Call-off three working days in advance
- Provision of travel cost, board and lodging
- Daily rate: € 380

3.3 Final Acceptance Testing

Web Download B.6 is an example Acceptance Test Plan ATP as carried out by other customers. This is proposed by Vexcel and must be accepted by Customer. Changes are possible and need an agreement by both parties.

3.4 Breakdown support

This has been previously addressed under the Maintenance Agreement (Web Download B.1). A replacement camera will be available as an option, should the repair in response to a support call result in more than 3 days down time. This replacement option is part of the Maintenance Agreement included in the quotation.

3.5 Sample of Processed Imagery Data

Web Download E addresses the issue of sample imagery. This consists of both a set of quick-look images for an overview over the full resolution images, and of data on a DVD to be ordered from Vexcel. Included are 6 images in two strips, in panchromatic format as well as in RGB and false color infrared format.

3.6 Training

Web Download B.7 presents the training plan for the UC-D, covering a total of three days in a first week, for two teams, one the aerial team for operation of the camera in the air, the other the ground team for post-processing and integration with photogrammetric processing software.

3.7 Help Information

The preliminary set of two manuals for users is attached as a separate Web Download D. One manual addresses the operations of the camera in the air, the other covers the post-processing operations.

3.8 Difference between Warranty and Maintenance

It was explained that the warranty addresses defects of the product, as described in a separate attachment to the Tender Response, and Maintenance is a much broader services including preventative visits, upgrades etc.

3.9 Is the Use of the Internet Customer Support System included in the Maintenance?

Yes.

3.10 Example of an SLA

More detail was requested on the MR 41. Vexcel's SLA is basically described in Attachment B.1 of the Tender response. This includes the use of the Internet-based Request Tracker system as the IT-support infrastructure. Recall the list of services as follows:

Repair of defective system and system components;
Preventative maintenance once annually;
Factory calibration, once annually;
Field calibration, whenever appropriate;
Routine software upgrades when they become available;
Routine upgrades of the manuals once they become available;
Telephone and email support.

Added to these services is the support via a loaner camera, should the product be out of order for an extended period of time, and should the OS request availability of a loaner.

The procedures to be used for the support are described in the Maintenance Agreement in conjunction with the Support Infrastructure Description in Attachment B.1 of the Tender Response.

Regarding the need for support, we do not have sufficient history to make a firm statement. In the photogrammetric scanner products, we have about 1 call per scanner per year, on average, and the time to resolve the issue is in hours, since it oftentimes is possible to fix an issue by Internet.

3.11 Manuals as Hardcopy and Online?

The manuals are available as hardcopy and as PDF (as part of the delivery and for download from the Vexcel Website).

4. IT REQUIREMENTS

4.1 Post Processing Computing Power

The post processing software can be executed on a single computer (also lap top) as well as on a network of computers. Each computer needs:

- Windows 2000/XP operating system
- Pentium 4 processor (recommended with hyper threading)
- At least 512 MB RAM (recommended 1 GB per CPU)
- Local disk space has to be:

  - ~200MB for software
  - ~400MB for each camera calibration
  - !!! ~280MB for the temporary Level-1 data per capture !!! (software has parameter to specify the number of temporary data at the same time)
- Network has to be at least Ethernet 100MBit, recommended is Ethernet Gigabit (can also be bundled to a 2 or 4 GB connection).
  Especially in case of SAN storage it can also be FibreChannel (2GB direct connection).

Due to performance reasons camera calibration data and temporary Level-1 data need to be stored locally.

4.2 Transfer of Data, Aircraft to Office

This has been discussed and reviewed in response to MR 15. The data flow options have been presented there. The quotation includes the Mobile Storage Units required to maintain the throughput specified in MR15. Concerning the concept of "office", there is the option of operating a "field office" separate from a "home office". Once harvested image data have been off-loaded from the airplane, a number of options exists to copy and post-process the images from level 0 into levels 2 and 3. These options depend on where post-processing software gets installed. The quotation currently assumes that only a home office will be post-process, and that a secondary post-processing license is used on a lap top or field office PC.

4.3 Customer Storage, Archive and Back-up Infrastructure

The simple response to this issue is the reference again to the fact that the UCD-images are TIFF or JPEG files exactly like scans obtained from film images.

The camera generates image data of different levels (described under Item 2.12). The corporate SAN has to store the verified raw data (Level-0) to be processed by different users. The processed images (Level-2) also need to be stored in the SAN for further processing and access. Level-1 data are only temporary data which should be created on a local disk of the processing computer.

Mandatory is the back-up of the Level-2 data. Optionally, the back-up of Level-0 data can be done for additional safety. Level-3 does not need to be back-up because it can always be re-generated from Level-2. The back-up system can be any (also existing) tape (robot) system compliant with the computer system and SAN. The processing computers have to be Windows 2000/XP.

The processing of Level-0 into Level-2 can be done by different users if the Level-0 can be accessed from different computers with the Office Processing software. The final product (Level-3) can be generated also by different users (computers).

An interesting response is the introduction of a product component called the UltraMap Server, quoted optionally (see the quotation in Web Download A). This Server could be set up as an UCD archive, catalog, post processing system and project manager. It is described in some detail in Web Download B.3, and in this use would be a component placed in front of the Customer's internal archive and catalog installation. The integration with the pre-existing Customer's archive and catalog system will have to be consider at the time of contract award.

4.4 Principles Of How Digital Imagery Is Produced

We described the principle of achieving a large format image from smaller elements, under Item IR5. Now the question is raised how the raw image is being created by each individual CCD.

As said before the UCD composes large format digital imagery using 13 area sensors, nine of them delivering panchromatic data, the remaining four producing red, green, blue and near infrared data.

The sensors are industry leading frame transfer charge coupled devices (CCDs), able to capture data with very high radiometric performance, i.e. at a dynamic of grater than 72dB. Every single CCD contains 4008 times 2672 net pixels which in term produces roughly 22MByte of image data per frame @ 16Bit/pixel.

The UCD design is fully modular. As a consequence, each CCD gets its dedicated data flow chain, including sensor electronics, digital signal processor (DSP), IEEE1394 interface (Firewire), PC module ("Working Units" WU inside SCU) and dual integrated set of Hard disk drives (HDDs).

The readout speed of CCD information is adapted in steps to the actual frame rate settings to maximize image quality (lower readout speed increases noise performance by making use basic physical principles).

Each sensor frame is stored in the native raw data format including header information, providing additional system data and unique identifier, to guarantee for a reliable postprocessing.

Synchronization between different CCDs is guaranteed by hardware trigger and handshaking lines.

The whole data generation process is strongly monitored by built-in self-test and error recovery means, partly integrated in the sensor hardware and partly realized in the WU's software.

4.5 Principles Of Post Processing Routine

The attached Manuals in Web Download D describe the process and method used to convert the raw images into deliverable level-3 color and false color images.

- Before processing the images in the office the data has to be exported from the camera (Level-00 to Level-0)
- The office software can process
  - Level-0 to Level-2 (Level-1 is not visible to the user)
  - Level-0 to Level-3 (in this case Level-2 is also kept)
  - Level-2 to Level-3
- Recommended is Level-0 to Level-2 and then Level-2 to Level-3.

4.6 Post Processing Routine Metrics

- Sizes of data per capture:
  - Level-0 has ~286 MB
  - Level-1 has ~260 MB (only temporary)
  - Level-2 has ~260MB
  - Level-3 depends on the format, e.g. Hi-resolution color (RGB or CIR) has ~250MB (8 bit) or 500 MB (16 bit)
- Processing times (Pentium 4/3GHz, 1GB RAM, 250GB SATA disk, all data local)
  - Level-0 to Level-2 ~4:00 minutes
  - Level-2 to Level-3 ~1:20 minutes

4.7 Captured Imagery Processing And Compression

The UltraCam currently is not using any compression of the imagery; therefore a compression discussion is not applicable. Compression is a planned feature, however to get implemented in future software release. However, compression will always be an optional capability to be used or not used by the customer, at his discretion. It is likely that by the time the system will be delivered, the Customer will have the option of compression, thereby being able to collect more than 2,770 images in a single mission without any landing.

4.8 Interface With Digital Photogrammetric Production Systems

The output level-2 and level-3 images are in principle rectangular version of scanned aerial images for standard photogrammetry. Therefore the typical stereo photogrammetric software systems should all in principle be able to process the UltraCam images into mapping products, using as the transfer format the TIFF and JPEG formats. Specifically, the following software packages have so far been reported to Vexcel to be used with UltraCam images, besides the Intergraph-Z/I and Leica Geosystems packages, including the new Leica LPS:

- Virtuozo,
- ISM-Diap/SysImage
- INPHO
- DAT-EM,
- KLT,
- Helava,
- PhotoMod,
- PCI
- And others

4.9 What Specification Are The PC's That Doing The Post Processing?

An example project results in about 423 images.

(a) The download rate from the SCU onto the MSU is at more than 45 images per minute.

(b) Downloading 423 images will take about 9 minutes.

(c) Post-Processing consists of running the Office |processing Software. This is typically done on a regular current (2004-) laptop at a rate of 4 minutes per image.

(d) Post-processing optimisation is the topic of the optional UltraMap Server product.

(e) The preferred post-processing PCs are two with 2 logical CPUs each for hyper-threading (Pentium-4, 3 GHz, 1 GB RAM)

4.10 What Are The Principles Of How The Images Are Stitched Together And How The Pan-Sharpening Works, What Algorithms Are Used Etc?

(a) The method of stitching consists of using overlaps among the 9 panchromatic CCD-images. These are being used to detect tie points by a corner detector, then the corners get matched to sub-pixel accuracy, the match points get used for efficient resampling.

(b) The 4 color bands get matched each to the resulting panchromatic image in a similar manner, but with adjustments to the algorithms, in particular in the case of the infrared band.

(c) Pansharpening is then applied in the transition from level-2 to level-3, and a transition from the 16-bit radiometric representation to an 8-bit representation is achieved. The compression to 8 bits is non-linear.

(d) The basic process is thus standard image processing/computer vision that can be implemented by any graduate student of computer science. What gets implemented will have to get researched by this graduate student.

(e) Can you accept that we consider the algorithmic details our expensively researched trade secret? For example, Digital Globe will not reveal its pansharpening process for its Quickbird imagery.

4.11 What JPEG Capability Is Available?

Current capabilities are JPEG 6.0, TIFF JPEG. JPEG2000 will be available by the 2nd quarter of 2005.

Note that Level-2 represents a “memory saving” and thus compressed representation of the color and false color images.

4.12 The UltraMap Server Software Running on Customer’s Pre-Existing Hardware

Given the Infrastructure diagram, Vexcel is requested to propose whether the Server software can run on the hardware that is already installed and in use at a customer site..

The UltraMap Server can be installed on existing hardware under two conditions. 1) There has to be a tape library compatible with the UltraMap drivers. The preferred vendor would be SpectraLogic. 2) The configuration outlined by the customer does not contain one or more servers dedicated for UltraCam Post-Processing. The performance of this particular installation will be compromised until such dedicated processing hardware is added to the system. A minimum of two dual-CPU servers is recommended.

The server requires a Linux machine which is connected to the tape robot library and which has Oracle and all the UltraMap software on it.

The server communicates with the other computers (Windows machines for processing). In the diagram the server would be a 5th computer in addition to servers 1-4. The UltraMap Server can use the SAN as central disk.

4.13 Can the Server Work with Oracle Geo-Raster Data?

Yes, after some minor modifications. The UltraMap Server uses Oracle spatial for all data management. Handling of Oracle Geo-Raster Data is therefore built into the system. Currently there is however no UltraMap Server user interface component to interactively ingest or manipulate such data. Geo-Raster Data need to be manipulated through the Oracle Database Management interface. The additional hardware and storage requirements need to be addressed separately.

4.14 Can the UltraMap Server Accept “Other Data”: LIDAR, Video….?

The data import/export system is flexible and can be extended. Yes, the UltraMap server is designed to archive and catalog any type of data, geo-spatial or not. New data types, however, require a custom extension to the software before they can be ingested into the system. These extensions can be customized to the specific needs of the OS to ensure OS internal (meta-) data conventions are fully supported.

We will enhance the UltraMap system under normal “to-do” version improvements at no cost to the customer, except the maintenance costs. Therefore we will not consider this extension an OS-specific, but a general feature of the product.

4.15 The MR12- Response on SAN Needs to Get Detailed in Light of the Infrastructure Diagram

The response to this issue is embedded in the previous items concerning the Infrastructure Diagram.

4.16 Mobile Server

Can two copies be made from the MSU-content onto the Mobile Server in one single operation?

Yes. The MSU (14 hard disks) are connected to the mobile server and the copy manager transfers the data to a specified destination (w/o backup, external disk or central SAN). The Mobile Server copies in a single operation the content of the 14 MSU disks onto one or two external disks. This is initiated with a single command in the user interface. Internally the software optimizes the data transfer by executing several copy processes in parallel.

Is the MSU transfer onto the Mobile Server using a single fire-wire?

The mobile server can be notebook (connection of MSU is then realized by external 1394 hubs), or a Computer with 6 PCI slots for the 1394 PCI cards. There are special portable computers that have up to 8 PCI slots as well as and integrated display and keyboard. The Mobile server uses a combination of 15 Firewire and 3 Firewire-2 ports to optimize throughput. As mentioned before, a total of 6 firewire PCI-adapter cards are used to guarantee the fastest possible data transfer rate.

Plug & Play

The plug & play of the external hard disks is fully supported by Windows XP and the copy manager software.

5. COMMERCIAL ISSUES

5.1 Costs

A formal “quotation” of the deliverable product and services will be presented on request after a specific requirements analysis, typically after a personal visit, by email or after a telephone exchange. This consists of a firm fixed system price for the basic configuration, plus some line items, which can be excluded or included in a purchasing contract. The quotation will be self-explanatory.

5.2 Payment Terms and Invoicing

Invoicing is in Euros from the Vexcel-office in Austria. Payment terms net thirty days after invoice are acceptable to Vexcel.

5.3 Inspection and Returns

Inspection Period from Receipt to Acceptance

The delivery of the product is proposed to begin with a visit of Customer personnel to Vexcel in Graz in Austria, to review the deliverables and perform a field test with a test flight in Graz, using Vexcel-resources. As a result, the Customer will “accept start of delivery” of the product, which is then shipped to the Customer.

Subsequent to this, as soon as is feasible, the product will be installed into the Customer aircraft and aircraft environment. Following the successful installation on the ground, a first test flight is performed, weather permitting. Then the training period will begin at Customer premises. This concludes the delivery process (“completion of delivery”).

Formal acceptance is then scheduled within a 4-week period, under mutual agreement, and after collection of imagery data in accordance with the acceptance test plan (see the separate Web Download B.6).

Return Procedure for Faulty, Damaged or Incorrect Goods

Should the acceptance test fail certain specifications, then Vexcel will be given a period under mutual consent to improve the system to pass the test.

Faulty, damaged or incorrect goods will be returned to Vexcel at no cost to the Customer, until acceptance of delivery has been achieved.

Money Back Guarantee

The Customer has the right to cancel this agreement without indicating any reasons. In that case the Customer will pay to Vexcel an amount of 10% of the contract value.

In the event that Vexcel fails the acceptance test and fails also the period to fix any violations of the specifications, Customer has the right to return the camera and to receive a full refund of any funds paid to Vexcel.

5.4 Quality Assurance

Quality assurance processes of Vexcel's key manufacturing partners are certified under the rules of ISO9000.

Manufacturing

An elaborate system of manufacturing tools exists at all manufacturing sites for electronics, mechanics and assembly, optics, shutters etc. Tests address each manufactured component, sub-assemblies as well as the entire system.

Examples include, but are not limited to:

- Testing for electronics functionality;
- In Circuit Test (ICT) for assembled printed circuit boards;
- Shutter vacuum and temperature tests;
- Lens quality tests;
- Disk air pressure tests in a vacuum;
- Focusing tests of each optical cone;
- Vibration testing.
- System functional test,
- Test run (5000 images minimum),

The Customer, if so inclined, will be welcome to visit the manufacturing sites at Seidl Electronics for the electronics component manufacturing, and at WILD-Austria, for mechanical parts manufacturing and assembly.

Calibration

Calibration is not only a determination of deviation of components and the system from an ideal status, and then correction for these deviations, but it is also a test of system functionality and stability. The calibration has been separately addressed in response to MR9.

Field Testing before Delivery

Each camera gets flown before delivery, and the test flight gets processed and a test report written with detailed results regarding image quality and geometric accuracy.

Field Testing by Customer

Specific tests in the field at the customer site serve to assure that the product quality meets specifications. This is further addressed in the item on Acceptance testing (MR 29).

Self-Checking of the System

As discussed previously under Item MR3, the camera has self checks which are feasible because of its design and internal redundancies. The error vectors in the stitching process serve as a quality assurance device in the field.

5.5 Service Level Agreements (SLA)/Key Performance Indicators (KPI)

Vexcel's new support system is tailored to the needs of Vexcel's special application needs, and it is currently being introduced. Therefore indicative figures cannot be given at the present time. In the meantime customer testimonials are available, showing our exceptional approach. A description of our support system is appended in Web Download B.2.

6. OPERATIONAL QUESTIONS

6.1 Annual Production of 50,000 sq.km. for Mapping at 1:1,250 to 1:10,000

Producing annually a coverage of 50,000 square kilometers would result in an annual "harvest" of 26,000 images with a GSD at 24 cm, and 160,000 images at GSD of 10 cm.

Therefore the mapping scales at 1:1,250 to 1:10,000 can be achieved with the GSD described here at 10 cm to 24 cm, for the ortho-photos with ground resolutions (meaning GSD or pixel sizes) of 10 cm to 25 cm, and with elevation accuracies for Digital Elevation Models at ± 20cm to ± 50 cm accuracy.

6.2 Operational Limitations

Flying altitudes	1000ft to 15000ft (guaranteed specs) ~750ft to ~20000ft (un-pressurized practical limits)

Because of our fast frame rate possibilities, the lowest possible altitude is influenced more by international flying rules instead of camera speed limitations. Optimum optical sharpness is given between 750ft and infinite object distance and could be further increased by reducing f-stop settings. The maximum flying altitude can be extended by making use of a pressurized cabin. Even without such cabin we have flown projects at 22 000 ft altitude.

Operating temperature	>0°C to 45°C (guaranteed specs)

Projects were flown at -50°C outside air temperature with no impact on camera operation.

Air Pressure	given by flying altitudes specs (see above)

Hard disk drives tested at less than 0.1bar.

Relative Humidity 5% to 95% (no condensation)

6.3 Increase Flying Opportunities

As indicated in papers attached in the Web Download C, unusual flying environments have not been an obstacle
to successful aerial photo operations. The increase in radiometry vis-vis film leads to a relaxed schedule for survey flights.

Typical exposure settings under optimum conditions (bright sunshine around noon) are f-stop = 8 to 11 and
Tv = 1/500 to 1/250s depending on geographic location and flying altitude. This gives a fully exposed image result with over 12 Bit maximum dynamic content.

By contrast, even results with 5 Bit average and 8 to 9 Bit maximum image dynamic could be evaluated experimentally (although the visual impression was somehow flat). In consequence the scene illumination under this circumstances (using f-stop = 5.6 and Tv = 8ms) can be lower by a factor of 1:250!
Results are excellent when flying “shadowless” under clouds.

6.4 Data Storage In The Aircraft

The data storage facility for the aircraft is the SCU, as previously described and as also described in the Web Download D (Manuals).

6.5 Project And Imagery Naming Conventions

The naming and organization of the Level-00/0/1/2 data is specified by Vexcel and can corrupt the processing if manipulated. The detailed information about the file naming and additional header information is described in the attached document in Web Download D.4.

Flight support data files or other meta data files (see attached manual of office processing, section meta data) and image files have a GUID (global unique id) as well as information of the camera and calibration. This ensures that the processing software can always and automatically match the data. The GUID can also be used as key in data bases.

6.6 Data Transfer Facility form a Local Mission Office to he Home Office

The data can be exported from the camera to the MSU (fastest way). Then either the MSU is transported directly or the data is copied to a central disk (or also tape) by using a “mobile server” (which can be a normal computer with enough 1394 firewire connection for the MSU and other disks. The data can also be saved twice to have a back-up copy onsite as long as the first copy has not arrived and verified in Southampton. The data can also be written to tapes that are then transported to Southampton.

6.7 Highlight, Shadow And Gamma Can Be Set For Each Band (Pan, R,G,B & NIR). How can the System Meet Requirements In a Specific Production Environment?

(a) Generally, the camera and its post-processing software produce “raw” input images for subsequent photogrammetric data processing. Orthophotos are the result of such a photogrammetric process and “color settings” are typically part of orthophoto software. However, independent of the orthophoto-process, the camera post-process also results in specific color values. The setting of the post-processing parameters for the level-3 output images is an automated process as described in the tender reply.

(b) Optionally, the user will be able to interactively control the parameter settings for post-processing to produce visually desirable level-3 color and color infrared images. The interactive setting of parameters uses a histogram editor, gradation curve editor and a preview function to visually understand the consequences of a particular setting

(c) User parameter selection to achieve the required histograms in 8 bits per color channel, with mean DN-values and standard deviations of DN-values in each color band to achieve MR6 will be available as a preparatory step before post-processing starts. Its implementation will represent a customization of the parameter setting and will be developed for the Ordnance Survey as part of the camera delivery.

Note:
This capability of achieving specific histograms is also available to users of Vexcel's UltraScan5000 film scanner and is routinely being applied in film scanning operations in the United Kingdom.

6.8 How Is The Radiometric Calibration Of Each Lens Applied To Create One RGB Radiometrically Balances Image?

(a) We are working on a field-calibration set-up that will consist of imaging in the field, transfer of the test images from the field to Vexcel and analysing the data at Vexcel. This will be available by the time of delivery, but no later than by the end of the 2nd quarter of 2005.

(b) A small part of an elaborate radiometric calibration is the lens-specific vignetting correction as a function of the aperture setting. This correction converts the raw 16-bit Digital Numbers of the level-0 images into radiometrically improved 16-bit level-1 image segments, as if the lens had no vignetting.

(c) RGB-processing follows in the transition from 16-bit level-2 to 8-bit level-3 images, using parameters as discussed in MR6 and MR7. The radiometric calibration of each lens is thus not directly related to the balance of the RGB-output images.

6.9 MTBF

The MTBF-question is known in terms of components, but not in terms of the entire system. Among the components all mechanically moving parts are considered to be the weakest elements in terms of MTBF. They are laid out in a way to exceed by far the expected operating hours of the complete system.

Examples:

Hard Disk Drives:	MTBF: 300,000 hours
Shutters:	MTBF: 1 Mio operations (successfully tested to 4 Mio operations)
Fans	MTBF: 60,000 hours

6.10 Please Explain How The System Will Fit Into An Existing Production Environment

(a) The easy answer to this question is the analogy to the precision film scanner producing TIFF images (or some form of compressed imagery), and this imagery gets transferred into an existing production environment that thus far has solely been fed by the photogrammetric scanner. In its basic and initial form, the digital camera produces the same data type as the photogrammetric scanner. However, this will be inefficient due to the new digital camera data consisting of 5 bands, not 3, and these bands being at 14 bits, not 8.
In conclusion: initially the digital camera data will be loaded into a pre-existing digital production system as if the digital data came from a film scanner.

(b) The new element in the digital camera domain is the fact that there now exist 14-bit (16-bit format) "level-2" data separate from 8-bit "level-3 data", uncompressed or compressed; and also 5 bands (panchromatic, R-G-B-NIR) as opposed to simply 3-band RGB. We have to assume that the Production System is not ready to take full advantage of the new digital sensor capabilities

(c) A more complex question is therefore how the transfer of image data (and associated flight data) can be achieved most efficiently into an existing 3-band, 8-bit Production Environment. We suggest that this efficiency maximisation be achieved by use of the optionally quoted UltraMap Server, in combination with a customisation project to take advantage of the pre-existing Production Environment and the corporate SAN system. The UltraMap Server, or its software, will need to get integrated into the SAN.

(d) We suggest that the customisation to increase productivity get defined once first experiences have been collected with the digital camera data flows. This will cause changes in the pre-existing production system and SAN. Vexcel will be happy to support this customisation and advise on the changes to the production environment and SAN, outside this Tender.

6.11 How Can Support Files As Well As Data Files Be Imported Into An Existing System

(a) The spirit of the response to this question is the same as for 2.12. Initially, existing production software will use the digital camera images and flight data in exactly the same way as scanned film images. The 8-bit per colour and the ideology of 3-channel images is the fundamental premise of existing photogrammetric software.

(b) A much more important issue than interfacing to existing photogrammetry software that has traditionally been using scanned film is the inability of this software to take advantage of specific digital camera capabilities. This will require that the photogrammetric software grow into a capability of using more than 8 bits per colour, use more than 3-band colour, become capable of coping with high overlaps efficiently and routinely. This is the responsibility of software vendors, not of the camera vendor.

(c) Various UltraCam-customers today employ the software listed in MR13. Sanborn (Colorado) use the Z/I Imaging ISAT. PASCO-Tokyo use Socet Set and the Leica Dodging software.

(d) Various ISAT and SOCETSET files are being produced by AEROoffice software; there is compatibility of the UltraCam and previous film cameras.

(e) Time to respond to this inquiry is too short to obtain specific customer comments on the specific BAE, Leica and Z/I software packages. If needed we will contact these customers to obtain testimonials on their use of these packages with UltraCam data.

6.12 How Is The MSU Used And How Does It Interfaces With The SCU When Transferring Data

(a) Specific Interpretation of the Question

The task is to maintain imaging capabilities for a continued duration of 24 hours in three 8-hour missions, one mission per day. The areas to be imaged are 5,000 square kilometers large, with a square shape and thus with a side length of 71 km. We assume that the area is 100 km dfrom the airport. Consequently, the following numbers apply:

Length of strip	71 km
Number of strips	78 km
Flying time per strip at 240 km/hour	1065 seconds or 0.3 hours
Time to turn from one flight line to the next, assuming 10 km	150 seconds or 2.5 minutes
Time for 77 turns	3.21 hours
Flying time for 78 strips	23 hours
Total flying time for block	26.21 hours
Total mobilization (2 times 100 km/day) and refueling stop (1 time per day)	9 hours
Images per strip	237 images
Images per block	16,825
Images produced per hour, excl. mobilization and refueling	624 images/hour
Images per 8-hour period	5136 images
Number of daily “harvests” of up to 2,750 images on SCU	2

(b) Concept of Operations for 3-Day Continuous Production at 8 Hours per Day

The project gets broken into 6 sub-blocks at 2750 images each, to be completed in 3*8 net flying hours. Data collection begins with a first aerial mission filling the SCU with the first 2,750 images. This takes 4.41 hours. Then the plane lands and the first batch of 2,750 images get downloaded onto the MSU#1. It is roughly mid-day.

The MSU#1 gets copied via the Mobile Server onto a large disk #1A. This takes about 10 hours and is completed before midnight. A second copy gets made by about 10 a.m. the next day (day 2), filling a second large disk 1B. MSU#1 is now no longer needed and can be erased at about 10:00 a.m. Of course there is no need to create the second copy on disk 1B from the MSU#1, since it could also be copied from disk 1A.

The second sub-block gets flown in the afternoon. The harvest gets downloaded onto the MSU#2, and gets copied onto a disk 2A, by about 2 a.m., and a second copy can be made onto disk 2B before noon on day 2. The MSU#2 is available for reuse at that time. Again, that second copy could be created off disk 2A and the second MNSU would then be free at an earlier time.

The third sub-block gets started in the morning of day 2, and on completing the third sub-block, it gets copied onto MSU#1, by about noon on day 2. The second day runs like the first day, with the fourth sub-block being downloaded onto MSU#2 in the late afternoon.

Continuing on in this manner produces the required result of collecting, downloading and backing up of the images that get collected during three consecutive 8 hour net flying periods.

(c) Optional Downloading in the Air
It is feasible to download images from the SCU onto the MSU in the air, as demonstrated by PASCO in Tokyo. In that case the plane will not land for a download, and will not refuel during the download.

Refer to Item 2.15 for additional information

6.13 Maximum & Minimum Operating Temperatures

The specified operating temperature range for the sensors is from –20 degrees C to + 60 degrees C. The formal system operating temperature range is between 0 degree C and +45 degree C.

However, the system has been successfully operated at –50 degrees C, for hours on end. The original Tender reply supported this statement by examples from South Africa (in excess of +45 degrees) and Norway (below – 50 degrees C).

However, it is recommended that the system after having been exposed to below zero temperatures, get warmed up before operations start.

6.14 Can The Mount Be Tilted In Flight To Enable Cleaning Of Lens.

The SOMAG GSM3000 mount can be tilted in flight to clean the lens, and to remove a protective cover, in case the plane has no door for the camera hole to protect the camera in transit.

6.15 What Is The Connectivity Of The Storage Units From Aircraft To Base Office (SCSI, Firewire Etc?)

(a) The data get offloaded from the airplane using the MSU and its firewire connections (disconnect the Sensor Unit SU from the Storage and Computing Unit, and connect the SCU with the MSU).

(b) Option A: The MSU can be shipped to the home office to get connected to the office processing system. Option B: The MSU-content gets locally copied via a Mobile Server onto a large LACIE-disk (see the optional UltraMap-Server). That copying process is also via firewire. The large disk gets then shipped to the home office and the MSU remains available in the field for the next “harvest”.

(c) Data from the CCNS and AeroControl systems are being copied on PCMCIA cards and are being transferred off the plane by the cards.

6.16 Is An Image Mosaic Of ‘Quick Views’ Built Up During Capture Of A Block Of Work? Can ‘Quick Views’ Be Viewed At The Same Time As Capture?

Recall that the UltraCam-system’s SCU is a 15-CPU parallel computer with on-board computing capabilities. The quick-views are computed in real time during the flight, displayed and saved. The quick-views are instantly viewable by the camera operator. Therefore the quick views can be viewed at the time of capture, with a delay of about 1 second, thuds typically well before the next image gets triggered.

An integrated image viewer built to use the quick-views for post-flight in-the-field checks as being built at this time and will be available by the end of the 1st quarter of 2005. The build-up of a “block” fro the quick-views is part of the image viewer.

6.17 Please Clarify The Processing Times Of Level 0 To Level 2 Per Image

(a) On a single PC or laptop, this will be 4:00 minutes once the data are local on the laptop.

(b) The processing is very parallel, and therefore using multiple CPUs will almost linearly improve the throughput. Network traffic will take some extra time and destroys the strictly linear improvement.

(c) On the SCU, the processing is at 1 minute per image, exploiting the multiple (but basically slow) individual CPUs inside the SCU.

(d) In the proposed optional UltraCam-Server, the processing is at a rate of 30 seconds per image

6.18 What Are the Project And File Naming Conventions.

In the current implementation, the project name will be given by the user. The internal file names are produced automatically by the system, and any UltraMap-Server archive and catalogue would use those names.

In Level-2 the project name can be changed in the office. The level-3 names are the customer-specific names as a prefix and suffix of the automated names.

A custom-naming system will be created for the Ordnance Survey after a specification has been created. This naming capability will be available at no extra cost. Creating this customized system is not a large effort.

6.19 Ensuring the Radiometric Consistency and Software Upgrades to Ensure this Consistency

I mentioned that a preliminary interactive tool has been provided to current UltraCam customers to obtain the same color in each image of a certain terrain location. An automated software upgrade is being developed at this time to enforce consistency as pat of the post-processing system OPC. This will be available at no extra cost at around the time of a camera delivery to the OS.

6.20 Geometric Accuracy Confirmed by Testimonials

The OS needs an independent confirmation from current customers about the geometric accuracy. Testimonials have been received within 24 hours from 4 customers. We quote from emails:

AeroData International Surveys

"*AeroData International Surveys, Deurne, Belgium, has processed several aerotriangulation projects based on UltraCamD images and direct georeferencing data (Applanix POS AV 510). The results were obtained by Socet Set and Orima software from Leica Geosystems.*
The relative accuracy of image measurements was in the range of ± 1.5 µm to ± 2.5 µm and the absolute accuracy was in the range of ±3.0 µm to ±3.5 µm."

Felix Schelling
Senior Production Manager, Aero Data

IFMS International Forestry Modelling Systems

"*We are using UltraCam D since spring 2004. Several mapping projects have been performed and aerotriangulation was applied by LPS software. The results from the UltraCam images were excellent, a sigma_o of ± 2.4 µm or better was achieved*".

Dr. Holger Eichstädt, Chairman
IFMS Pasewalk, Germany

INPHO GmbH, Stuttgart

"INPHO GmbH, Stuttgart, has successfully used digital image data from the UltraCamD of Vexcel imaging Austria for aerotriangulation. We have noticed a sigma_o a posteriori of less (better) than ± 2 µm. The fully automatic workflow of our aerotriangulation package Match AT (automatic tie point measurement) was applied. The interior orientation of the camera is predefined by the camera definition, thus no fiducial measurements were needed.

Selected Projects

Project 1: Austria 11 cm GSD 44 images 80% forwardlap 60 % sidelap sigma_o: ±1.89 µm
Project 2: Germany 14 cm GSD 120 images 80% forwardlap 30 % sidelap sigma_o: ±1.97 µm"

DI Josef Braun, Senior Engineer
INPHO Gmbh Stuttgart

PASCO Corp, Tokyo

"*We are using UltraCamD images for aerotriangulation. The results from LPS processing was in the range of ± 2.5 µm to ± 3.6 µm for sigma_o. Project results from Match AT have shown a sigma_o of better than ± 2 µm (Shinjuku Block, July 20th, 2004, GSD 20 cm, 3 flightlines, 24 images, sigma_o ± 1.89 µm).*"

Mr. Kikuo Tachibana
PASCO CORP. GIS Institute
Higashiyama-Building 4F
1-1-2 HIGASHIYAMA MEGURO-KU TOKYO JAPAN 153-0043

6.21 Post-Processing Throughput to Level-2 and Level 3

On a laptop, I clarified this to be at 4 minutes for Level-2 and another minute for level-3.

6.22 What is the Weight and Size of the MSU?

11kg, 460 mm x 290 mm x 255 mm

6.23 For an Operation as Described in item 2.15, How Do the Images Get off the MSU?

The data from the MSU is copied as described in point 10 (using the mobile server in the field).

6.24 Can Color Get Processed for Each Image Independently

Yes. In addition, new software is being implemented at this time to enforce that one location on the ground has the same color in each overlapping image.

6.25 Blur Detector Schedule

I confirmed that we are planning a releasable blur detector during the 2nd quarter of 2005.

6.26 Quick Image Review?

The in-flight quick-views generated and displayed during recording can also be re-displayed by using the image viewers on the camera (SCU). The operator can scroll through all images between the flight lines or after landing. He also can do a virtual “re-fly” (slide show).

6.27 Tagging of QuickViews on Board

This is currently not yet available, but can be easily added as part of the normal software updates, made available to customers as mart of the support system. The operator already can navigate through all quick-views and (select/deselect) images for export or processing.

6.28 Merging the Three Independent Data Streams from FMS, DGPS/IMU and UCD

Additional data from the FMS, GPS / IMU (meta data) can be merged into the file header of the images during the office processing (in Level-2 and/or Level-3). The GUIDs (global unique ids) in all files are used to match the information automatically.

Planned feature: Put the meta data into the header of the raw files right after recording (before they are exported from the camera). This will be part of the normal updates of the software available under the maintenance/support system.

6.29 Drift Control in Stabilized Mount with CCNS-4 and if no CCNS-4?

Various possibilities exist to control the rotational angle for the camera mount presuming CCNS4 is present (sorted comfort-wise):

(a) Manual control: Before reaching the flight-line the pilot has to point the nose of the airplane in the direction of the flight line for a short period of time. During this time window the camera operator resets the mount manually. After that the pilot may compensate for a possible side-wind influence again and the mount keeps the zeroed position by means of the built-in gyros. This works well during a certain time span, during very long flight lines the influence of the gyro drift might be noticeable.

(b) Continuous manual control: Making use of an external accessory box, the operator is able to set the target angle of the mount by turning a potentiometer knob. Now he is able to read the residual error angle from the CCNS4 display and to compensate for that.

(c) Fully automated mode: The mount has to be connected to CCNS4 and to the airplane compass. This solution has to be explored depending on the actual instruments in use.

Note that the add-on feature from IGI to directly have the CCNS-4 run the drift control of the mount is as follows (from IGI):

IGI DCI-01-002 interface and cable for operating a Leica PAV-30 mount	EUR 3.820
For operating the PAV-30, Leica has to supply the "COM option" for the PAV-30, at appr.	USD 7,000

7. FUTURE TECHNOLOGIES

7.1 Roadmap

A 2-4 year roadmap is a rather difficult issue to reliably present both internally to the employees and owners of a company, let alone to the outside market. What one generally will need to expect is that the data collection, storage and transfer solution will undergo a rather rapid evolution, in tune with the Moore principle (improving the cost benefit ratio of computing every 18 moths). According to this principle, a 10-fold improvement will become available across a period of 5 years.

Clearly, all software will grow in functionality continually, resulting in improved performance, robustness and functionality. This will lead to new versions of existing software under version control, as well as to add-on products being offered.

Additionally, of course the sensor unit, thus the “heart” of a camera, will be upgraded continually. Improvements will affect the current product but not represent a new camera model. However, a changed specification of a new camera is likely to appear in the 2-4 year time frame. It needs, however, to be pointed put that the Moore principle is not applicable to CCD developments; those are much slower than computing developments.

7.2 Technology Refresh

As the on-bard storage and computing innovations become effective, Vexcel will propose an upgrade path that is very favorable to its customers. Details will have to wait until the costs of such innovations are understood, and until the feasibility of the upgrade path has been verified.

Software-only innovations can be separated into three types: first, improving existing software in performance and stability, and updating it for new versions of the operating systems; second, adding functionality to existing software; third, creating add-on software for new, previously unavailable functions. The first type is being made available by Vexcel to its customers as a part of the maintenance agreements at no extra cost. The second type is being sold as an upgrade to existing customers, for a reduced price if a maintenance agreement exists. The third simply is a new product.

Any changes in the sensor can be reviewed in the annual factory calibration and re-certification. Upgrades to improve performance or stability are part of the maintenance agreement. This does not change the specifications of the camera, therefore the parts and labor are included in the maintenance agreement.

For improvements leading to a new camera model, thus a camera with different specifications, an upgrade path will be defined for existing customers for a favorable implementation of the improvements in their product.