FRAME CAMERA (UCD) VERSUS "PUSH-BROOMING"

The major two technologies for aerial large format digital imaging are the frame imaging approach as implemented in the UltraCam-D (and others), and the linear array technology used in satellite remote sensing and adjusted by Leica for aerial operation in their ADS-40. This later technology has come to be called "Push-Broom Sensing".

Leica is presenting comparisons between the two technologies claiming numerous advantages of their "push-brooming" approach. What one will notice is that the Leica-claims address technology and color issues, not however the most important topic of photogrammetric imaging: **the geometric accuracy**.

It is necessary to examine these Leica-claims and to determine whether they are significant or contrived. In the process we do not speak much about geometric accuracy, since this is being largely left un-addressed by Leica. The following points are presented in the form of Questions.

QUESTION: ARE THERE ANY KILLER ADVANTAGES OF FRAME IMAGING OVER "PUSH-BROOMING"?

Yes, there are at least 4 as follows.

Killer Advantage 1. Frame Imaging Can Produce Smaller High Quality Pixels (Is Therefore Applicable Also at Larger Applications Scales)

The linear array technology of "push-brooming" cannot implement forward motion compensation. Leica's statement that *"Forward motion compensation is inherent in the push-broom concept"* is incorrect, since it ignores the exposure time issue. Therefore the pixel size is defined by the flying velocity and exposure time. At reasonable signal-to-noise values such as 72 db, an exposure of 2 milliseconds will be needed if there is good light (sunshine in the middle of the day). At that exposure and at a flying velocity of 75 m per second, the pixel smear will be at 15 cm.

If an image with a pixel size is shown at 5 cm from "push-brooming", it is taken with a 1 millisecond exposure time (1/1000 second), no color, and a slow plane flying at 50 m per second. This is not an operational specification but a very special case.

Practically, 2 msec is already a very short exposure (dwell) time, and planes flying at 50 m per second are not typical. Therefore certain "push-brooming" owners state that they cannot achieve smaller than 20 cm pixels. That limits the applicability of the "push-brooming" to small-scale work. That work is analogous to a film scale at 1:10,000 scanned with 20 µm pixels. Equivalent film scales larger than this will not be feasible in a routine manner with "push-brooming". What will the "push-brooming" user do for larger scale work? Continue with film? Or buy an UltraCam?

Killer Advantage 2. Frame Imaging is Compatible with Current Workflows

Current workflows rely on the image as a carrier of geometric information, and on individual image frames. The strip image concept of "push-brooming" is incompatible with that tradition. Therefore a separate workflow is needed for "push-brooming". Multiple operational systems will need to be maintained one for large scale mapping and another for "push-brooming" at smaller scale mapping.

Killer Advantage 3. Frame Imaging Offers Superior Redundancy Options

The 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.

The overlaps in “push-brooming” are fixed to 67% and each object point is on 3 images only (forward-downward-backward). In addition, the color values are observed once per object point, whereas a framing camera produces multiple color observations, one per image taken. Thus in an 80/60 overlap scenario, 20 color values get observed and an “Incidence Angle Signature” can get developed for certain objects.

Killer Avantage 4. Frame Imaging Produces High Geometric Accuracy by Menas of Aerial-Triangulation versus the Push-Broom’s Reliance on GPS/IMU Measurements

“Push-brooming” produces raw imagery that has no internal photogrammetric accuracy. Therefore the geometric accuracy must be obtained by direct geopositioning using a GPS/IMU combination. This accuracy is limited to that which the GPS and DGPS-data provide. This is particularly compromised in height and has a limit of perhaps ± 20 cm in each image.

In contrast, an Aerotriangulation (AT) is feasible with frame images, so that AT-based accuracies can get achieved that can reach values of better than ± 1 pixel (± 3 cm?). Additionally, the AT can be performed fully automatically.

There remains the argument that an AT needs ground control points. That is not correct. An AT can be based on DGPS-observations just as direct geopositioning is using. The DGPS-observations can be synchronized with the image trigger and as a result, the DGPS accuracy gets combined with the AT-accuracy for higher relative (internal) accuracies than the direct geopositioning can produce.

The AT-based accuracy is more stable, higher and better suited for stereo measurements and vector collection. Just imagine the compromised stereo model if the two independently geo-located images have ±20cm uncertainty each, randomly distributed across each image that combine to a false stereo parallax at ± 30 cm.

LEICA’S 19 CLAIMS ON “PUSH-BROOMING” ADVANTAGES

Question 1. Leica Claims that its “Push-Brooming” Technology Produces Higher Resolution Images than a Frame Camera Can; Is that True?

The spatial resolution of the “Push-Brooming” sensor is limited because of the dependency on the aircraft speed over ground and exposure time (e.g. at an exposure time of only 2 msec the aircraft moves about 15 cm at a speed of 75 m/sec). That motion blurs the “push-brooming” pixel.

Leica’s comparison of “push-brooming” and framing cameras at GSD = 20 cm is <u>not presenting the frame camera’s end product</u> (the end product is the pansharpened high resolution color image). Compare the image samples below to understand that the color quality of UltraCam images match the quality of push-brooming (e.g. the bright crosswalk on the street).

Note that in the case of “Push-Brooming” the resolution is limited to 15 or 20 cm GSD. The GSD of 8cm cannot be produced by “Push-Brooming” at a high quality (cf. also Killer Advantage 1).

ADS40, GSD = 20 cm UltraCam D, GSD = 20 cm UltraCamD, GSD = 8 cm
(Courtesy PASCO-Japan, owner of 3 “push-brooming” and 2 UltraCam-D)

Question 2. Is Leica’s Claim True that a “Push-Brooming” Full-Color Image is Superior to a Pansharpened Color Image from a Framing Camera?

The pansharpening method has a tradition and is well known from remote sensing applications (e.g. IKONOS-, Spot-, Quickbird- and other images). Please note that framing cameras produce all 4 color bands simultaneously (not the case in “push-brooming”) and all color bands are co-registered to the high resolution panchromatic channel exploiting the rigid geometry of the frame concept.

The color bands from “push-brooming” are registered line by line and the entire image quality is depending on the ability of the active mount to compensate unexpected movements of the camera caused by air turbulences.

In addition to this geometric advantage is the ability of framing cameras to choose the exposure time according to the light conditions, which therefore is not based on the speed over ground; this is much superior to the push-broom concept and finally produces a better radiometric resolution in the color bands.

On this specific issue, note also that pansharpened imagery has been compared to full-color images using the edge sharpness measure, stereo matching, image classification, and in all cases, there was no difference found between a pansharpened image and the full color image. In fact, such quantitative assessments illustrate the advantage of pan-sharpened color frame images over scanned color film.

The “push-brooming” users do not tell the full story. Because of radiometric limitations, “push-brooming” is often used with color bands collected at twice the pixel size than the panchromatic channel. This results in pansharpening also, typically with a factor 1:2.

Please review more details on this important subject in the technical paper by R. Perko Digital Pansharpening Versus Full Color Film: A Comparative Study, 2005, 6 pages (see the downloads).

Question 3. Is Leica's Claim True that a Continuous Pixel Carpet of "Push-Brooming" is Preferable Over a "Patchwork" Block of Frame Images?

The frame images have a long tradition in photogrammetry. Stereo Workstations are able to handle such images and the geometric background is well known (cf. also Killer Advantage). AT results are reliable and can be proofed by additional GPS and IMU measurements e.g by integrated sensor orientation. The handling of frame images at a files size of typically 0.25 to 0.5 GBytes is much more comfortable than the handling of large pixel carpet files of more than 2 Gbytes.

The pixel carpet concept has a geometric instability (no geometric stability whatsoever). The "patchwork" (= photogrammetric block) has a proven and well-understood stability expressed in the concept of the "Sigma-nought σ_0".

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

The total number of pixels for a project may be the same from either imaging technologies. They get, however, organized differently. Once the exterior orientations have been determined, there is no difference in the comfort of accessing and using the data.

Question 4. Is Leica's Claim Relevant that the Single Lens of "Push-Brooming" is Preferable over Multiple Lenses in Frame Cameras?

One has to understand the full photogrammetric concept. The single lens system of "push-brooming" has advantages and disadvantages. The need to expose all 10 linear CCDs in the focal plane requires a high quality lens system. However, each linear array is at a separate geometric location, and therefore the color values are not collected at the same time for the given object point. Imagine 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 image stability, since there is none. It is all based on the GPS/IMU observations.

The co-registration of true color and color infrared is difficult (Leica offers different concepts of focal plane designs with r-g-b and nir-r_2-g_2 in order to overcome this).

Question 5. Is Leica's Claim Relevant that the "Push-Brooming" CCDs Have No Errors, the Framing Camera CCDs Have Damaged Compromised Pixels?

It is correct that single line CCD-sensors do typically not have dead pixels; if they did, there would be no way to interpolate a gray value two-dimensionally, but only linearly within the CCD-line. But this observation by defenders of the "push-brooming" technology is only true if one limits oneself to the point of view of the sensor. From the point of view of the photogrammetrist the geometric rigidity is relevant, and the frame camera is simply superior to the push broom concept. A small number of compromised pixels does not change this fact. The compromised pixel issue is vastly exaggerated by the "push-brooming" afficionados, since of course the quality of the frame CCDs is proven and only selected highest quality CCDs are used for the UltraCamD (less than 50 pixels in 11 million pixel array are compromised).

We need to stress at this point that the "push-brooming" does produce missing pixels, but not due to missing CCD-elements, instead they are being missed if a sudden uncompensated motion occurs by the airplane. Entire objects may disappear in such a case.

Finally: the frame camera has a much richer option to produce overlaps. Since they are cost free, such overlaps offer a wider range of options to select an output color pixel in an orthophoto from perhaps as many as 20 input pixels. In comparison, the "push-brooming" has only one single color observation per object point. It would therefore be catastrophic if the "push-brooming" had a missing pixel, whereas the frame camera can easily live with 19 of the 20 input pixels, should one be compromised.

Question 6. Is Leica's Claim Relevant that "Push-brooming" Operates Without a Shutter, and that Framing Cameras Have 8 Shutters?

It cannot be a disadvantage for a camera to be operated via a shutter, because this creates the exposure time and a choice of these times. This has a pretty long tradition. And the exchange of a shutter in the field is a requirement for a good frame camera, as is the constant monitoring of the shutter function to support the shutter exchange program At 4 million operations as mean-time-between-failures, the shutter is not a real issue in camera stability.

Question 7. Is Leica's Claim Relevant and True that Framing Camera Lenses Have Compromised Corners, and that the "Push-Brooming" System Images in the Center of its Lens?

This is only true for the nadir view. The forward and backward views (and the single lens concept of the "push-brooming") causes also a large image height and therefore the same optical basics as frame cameras operate with.

Question 8. What is the Value of Leica's Point that the "Push-Brooming" Pixel Carpet Appears Simpler than the Multiple Stereo Models of a Framing Camera?

Digital "push-brooming" image files at a size of 250 GByte to 500 GByte are much harder to operate with then are the many smaller 0.25 GByte files. Just think of a user wanting to use Adobe Photoshop and having to open a very large file. And this is even more distinct when dealing with stereo images. Photogrammetrists are used to operating with multiple images in geometrically well-defined image blocks. This "push-brooming" argument seems contrived.

There exists the concept of "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. "Virtual Seamlessness" invalidates the pixel-carpet versus "patch-work" argument.

Question 9. And How About Leica Emphasizing that "Push-Brooming" Produces Fewer Files then a Framing Camera?

This arument by "push-broom" defenders repeats the issue of Question 8, reworded. It is definitely a disadvantage to have fewer larger files than more smaller ones. The entire number of pixels over a project area remains unchanged when talking about the same ground resolution. Fewer files must be larger in size from this point of view. And very large files can only be handled if special software is available (e.g. the well known Adobe Photoshop software is limited to an image format of less than 32 000 pixels in x and y). In stereo processing, this issue becomes even bigger.

Given "virtual seamlessness", this "push-brooming" argument appears contrived.

Question 10. Is Photo Interpretation of a Pixel Carpet Simpler than the Use of Many Frame Images

Again, we see a repetition of Question 8. In response, photogrammetrists have been trained to interpret frame images since decades. And common photogrammetric digital workstations

support the concept of "virtual seamlessness" today, so that one can switch between stereo images or single images without interrupt.
This makes it possible to roam seamlessly through the entire project area. The pixel carpet may have an additional disadvantage: the huge size of the image files, which are finally also limited to a distinct area.

Question 11. Leica States that the "Push-Brooming" Pixel Carpet Has More Uniform Image Quality than the Multiple Patchwork Frames

First, this argument in favor of "push-brooming" ignores that image quality in photogrammetry has also to do with geometric quality. Depending on GPS/IMU measurements and also depending on the quality of the active mount (depending on random air turbulences) the image quality of the pixel carpet cannot be homogenous from a geometric point of view.

Second, image quality is being affected by the need to correct sudden motions of "push-brooming": some ground points may not be imaged at all, some others may be imaged twice. How is the resulting geo-referenced image going to cope with these changes?

Thirdly, frame image radiometric quality is a result of software. This is currently evolving into automated radiometric measurement systems, and into automated block adjustment systems for radiometric values. High redundancy is available from overlaps along the flight lines; "push-brooming" defenders seem to consistently ignore this advantage of framing over "push-brooming".

Question 12. How About Leica's Claim that "Push-Brooming" Color Composites Produce Better Geo-Referenced Pixel-Accurate Products Than a Framing Camera?

This is definitely not true. The geometric accuracy of a "push-broom" camera has only one source- the GPS/IMU subsystem. We know from several publications, that ADS40 accuracy is accurate within ± 0.5 to ± 1.0 pixels and the accuracy of frame -cameras (DMC as well as UltraCam) are accurate within ± 0.15 to ± 0.2 pixels.

Thoru Yotsamat et al., PASCO Corp,. report in their contribution to the ISPRS Commission I Conference, Denver, CO, 10-14 Nov 2002 '*Investigation for Mapping Accuracy of the Airborne Digital Sensor ADS 40'* on 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 report in the same symposium in their contribution *'Geometric Calibration of the DMC: Method and results*' an accuracy of ± 0.23 pixels in X and Y and ± 0.39 pixels in Z (σ_0 = ± 2.4 µm or ± 0.2 pixel). Investigations with the UltraCam D have shown that the σ_0 of AT-results is consistently better than ± 2 µm. This is 1/5 to 1/10 of a pixel! This is a geometric performance which definitely is far superior to "push-brooming" with its ± 1 pixel result, but limited to ± 20 cm in height.

Question 13. Does "Push-Brooming" Indeed Have Better B/H Ratio than Digital Frame Cameras?

Wrong. At an 80% forward overlap from frame imaging, images 1 and 5 combine to a stereo impression at 0.5 B/H-ratio, not that much different from traditional wide angle film images at a B/H-value of 0.6.

The "push-brooming" claim assumes a 60% forward overlap for the frame camera, which is arbitrary. The "push-brooming" itself operates with a 67% forward overlap and cannot change this. It's B/H-value is therefore in the range of film images.

Question 14. Leica States that “FMC is Required in Frame Cameras, whereas “Push-Brooming” Has Inherent FMC” – Is that True?

An invalid argument. The purpose of the FMC is to increase the exposure time, not to remove image motion. Image motion occurs because one wants to take better images by the use of longer exposures. The frame camera can operate without FMC by simply eliminating motion via shorter exposure times.

The “push-brooming” argument inverts this: because this has have no control over exposure time, it does not need FMC. And this produces the contrived claim that FMC is “system inherent”.

Question 15. Leica Claims that for “Push-Brooming”, All Parts are from Leica and Integrated, whereas Frame Cameras Use Parts from Multiple Suppliers and are Poorly Integrated. What is the Merit of this Claim?

Integration is a two-sided sword. It means that the customer is totally dependent on the vendor. In the Vexcel-case the design choices were made to be compatible with the pre-existing world of work flows in the office and in the air, to make maximum use of what legacy exists.

Leica calls this a “lack of integration”? The integration can easily be achieved with third party vendor components such as IGI, Trackair, Applanix.

Experience tells us that this Leica argument is as contrived as some of the earlier ones.

Question 16. Leica States that “Push-Brooming” Has Only 7 Spectral Files, Whereas Frame Cameras have a Large Number of Spectral Files. Is this Relevant?

Again: more files means the same information is distributed across smaller data sets and is easier to manipulate in parallel. What is so great about having 7 huge files for a project, as opposed to having 1000 small files as long as the software provides the user with an automated and “virtual seamlessness”?

Leica repeatedly attacks the idea of the photogrammetric block and substitutes for it a wobbly pushbroom pixel carpet that has no real benefits to the user, yet presents a disadvantage as if it were a significant benefit to the user.

Question 17. Leica Claims that “Pansharpening is not Suitable for Remote Sensing”. Is this True?

There is no evidence for this claim. All the experimental work we are familiar with proves that this claim is incorrect. In contrast, the multiple imaging using 80% overlaps produces a new remote sensing tool, the “incidence angle signature”. In addition, the texture versus color measurements need to be considered as well. The focus on only the original (and in fact singular) color observation is misleading.

The sample images to support Leica’s argument distort the truth by using images from “push-brooming” flown over one forest area and then a frame camera image from another area, taken at another time, under different lighting conditions, so the image contents cannot be compared.

Question 18. Leica States that Frame Camera Components Are Off-the-Shelf, “Push-Brooming” is All Special Purpose. Is this True and Relevant?

Why is it a disadvantage when a product uses parts that are easily and globally available, and if as a result the product is less expensive in the initial purchase, and has lesser maintenance costs? This reads again like an inversion of the truth: the product costs and operational costs need to be addressed, not where the parts come from.

Question 19. Leica States that “Push-Brooming” Has Better Spectral Band Separation (Narrow Band Filters). What is the Merit of this Claim?

Filter choices can be made to optimize compatibilities with color film, with spaceborne sensing, and with specific applications such as forest inventories.

One issue is the amount of light needed to make a image. The narrower the filter band, the less light is available and the more one compresses the radiometrics.

Which filter to use is a rather soft concept. There is no basic difference between the “push-brooming” technology and the framing technology that would result in a filter difference imposed by the imaging principle. So this argument seems contrived.