UltraCam
Photogrammetric Digital Aerial Cameras
The New Standard of Excellence for Aerial Mapping

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1. BACKGROUND

Over the past two decades, aerial surveying and photogrammetric map production has moved steadily towards a fully-digital workflow. Clients demanded digital map products, such as feature files containing planimetric and topographic details for ingest into CAD and GIS, or DTM and orthophoto products. But at the heart of this workflow was one key analog step which was proving tougher than any other to replace with a digital equivalent: flying with film. For many organizations, the flight department is the most capital-intensive, and operationally the coordination of flight logistics with clear skies is fraught with risk. For every project, getting good film “in the can” was a major milestone.

By 2002, the first pushbroom sensors and large-format frame cameras designed specifically for aerial mapping applications had been announced and early adopters were making major investments in sensors and flight support infrastructure. These pioneers had to make investments of well over $1m for the sensor payload and supporting systems in the aircraft, and upwards of $500k in IT systems just to handle the initial processing of the raw imagery. To further the challenge, software to handle pushbroom imagery was not immediately delivered together with the sensor.

With interest heightened by industry discussion of these first uses of digital aerial sensors, questions remained for mapping organizations who conducted aerial surveys and especially for managers of smaller, private-sector aerial mapping companies:

- Can I afford to purchase a digital camera?
- Can I afford not to? What is the future of my business if I do not?
- Is the digital camera up to the job? Can it replace the familiar film camera, and can it meet the quality and accuracy requirements for all my clients?
- How do we make ourselves ready for the new camera?
- Will the new sensor allow me to deliver better products and service to my customers?
- Will my customers ask for and accept the new digital data?

2. CHALLENGES

The challenge then, was to remove the last remaining analog component of the aerial survey workflow and to create a streamlined, fully-digital workflow, without compromising key characteristics of image quality and accuracy, rather with the goal to even improve quality and accuracy. Furthermore, this transition should improve the efficiency of the aerial survey operation and allow the delivery of final product faster and more reliably, and support the wide range of project requirements typical to a survey organization.
A second major challenge was less well-defined, but implicit: how to leverage this new fully-digital work environment to be able to deliver something radically new, something that could transform the organization, attract new customers and build new business.

3. ALTERNATIVE APPROACHES AND CONSIDERATIONS

During the past decade, alternatives to large-format frame imaging have been presented as options for aerial imaging and mapping applications. These include pushbroom sensors, small- and medium-format frame sensors, approaches using multiple small-format imagers in fixed-mount or gimbal-mount arrangements.

### Pushbroom Sensors

Pushbroom sensors for mapping were first introduced by Leica in 2000, and their use has evolved with an emphasis on large-area orthophotomosaics. The pushbroom approach brings with it many well-documented disadvantages when it comes to acquiring high-quality, geometrically consistent and robust imagery, resulting from the fact that the imaging quality and dynamic range is directly related to the speed of the airborne platform. The effective footprint of a pushbroom-captured pixel also varies in shape as a direct function of groundspeed and altitude. Finally, pushbroom imagery has no inherent geometric strength, and is totally dependent upon sophisticated processing of airborne GPS and IMU data and timing, to generate imagery useful for metric applications. Refinements in electronics and processing can minimize but not completely remove these inherent challenges. Pushbroom sensors are still active in the marketplace, but largely used for orthomosaicing projects where efficiency and photogrammetric accuracy are not the most important or over-riding factors. Even vendors who once defended pushbroom technology now recognize the strength of framing sensors and offer both. Fundamental limitations of pushbroom technology cannot provide the flexibility and control of exposure at a broad range of flying heights and conditions, without affecting image quality.

### Small-format Imagers

Although the boundary between small, medium and large-format imaging sensors has evolved during the past 10 years, it is still useful to consider these broad categories. A major consideration in the operating cost of an imaging sensor is the time and cost of imaging flight miles, therefore a function of image swath width, field of view, and the time required to reach and descend from imaging altitude. Small-format imagers consequently require a larger number of flight lines and image frames, increasing the post-processing effort required for any photogrammetric applications, including aerial triangulation, DEM extraction and orthomosaic generation.

### Multiple, small-format frame / ganged in fixed or gimbal mounts

An alternative approach, based on small-format cameras in fixed or gimbaled mounts, offer the capability to cover wide areas from high-altitude. However, their performance is compromised by the use of Bayer pattern sensors and a complex processing chain. Furthermore, their effective field of view providing broad area coverage is associated with high altitude, meaning that image quality may be further degraded by atmospheric conditions. For those designs based on a gimbal mount, raw image
capture is further complicated by the fact that individual frames are acquired while the gimbal is moving cross-track at the same time the aircraft is moving forward. This reduces possible flexibility in controlling exposure and shutter aperture and also necessitates additional image motion compensation (in two directions).

**Monolithic large-format frame**

It is perhaps easy to consider a digital framing imager utilizing a single CCD frame sensor. In theory, there should be benefits to this approach, but in practice there are two very basic and practical challenges to realizing a successful imager design. The first is that the cost of constructing such a monolithic sensor to the exacting specifications of geometric and radiometric quality has been prohibitive. Secondly, and just as critical, the volume of data which must be transferred to achieve a single frame exposure necessitates very high bandwidths within the sensor itself as well as the supporting electronics. Even today, monolithic large-format imagers must compromise in terms of framing rate and image dynamic range.

### 4. The UltraCam Approach

The original UltraCamD model, first delivered by Vexcel Imaging in 2004, embodied a camera system which strongly leveraged software in order to achieve operational efficiencies and performance which met the requirements of aerial photogrammetry. Its primary, patented design innovations reflected a focus on both geometric fidelity and operability:

- Use of multiple sets of optics with a very specialized exposure concept based on syntopic exposure
- Photogrammetric processing to create single-perspective view large-format frames with known stability
- Distributed processing both in-flight and on the ground to achieve a high refresh rate, significantly better than two seconds between successive full-frame exposures (twice as fast as the best-performing film camera)

This approach combined rigorous and well-proven principles of photogrammetry with an innovative design of electronic, optics, and data processing. The original concept of the UltraCam was simply to replace the film camera with a digital camera, in order to avoid disruption of other operational steps before and after imagery collection. One of the key advantages of the large-format frame digital camera was its compatibility with photogrammetric software used for aerial triangulation, DTM generation, orthophoto production, and stereo-compilation. This meant that the arrival of the UltraCam did not require a total replacement of existing production hardware and software and procedures already in use, and in fact this holds true today and is one important reason for UltraCam’s rapid acceptance in the marketplace.

But it soon became apparent that the performance characteristics of the UltraCam lay the foundation for a radically new workflow, attractive for its potential to greatly enhance productivity.
Key enabling elements of this were:

- Full exposure control (aperture, shutter speed) across all types of terrain
- Geometric quality: stability and accuracy within each frame better than 2 microns
- Image quality: high dynamic range of image capture of almost 13 bit with very low noise, 14 bit A/D conversion, 16 bit image processing workflow
- Integrated GPS/IMU to provide ancillary data for each exposure
- High framing rate permitting high-overlap imaging (better than 2 seconds between frames)
- Distributed processing to permit high throughput (in-flight and on the ground)

From the UltraCamD, the product range progressed with the introduction of the UltraCamX in 2006, and the UCXp in 2008. With each successive UltraCam model, the supporting infrastructure of hardware and software components has become more refined and better engineered. The most obvious characteristic was the reduction in size and weight, simplified connectivity (as reflected in a smaller number of cables), and better integration with ancillary components such as the flight management system. These models increased the effective swath width to 17,310 pixels for the UltraCamXp, but just as significantly, introduced better performing electronics and more mature data handling and systems integration.

As the product family further matured, the UltraCamL was introduced in 2008 as a large photogrammetric medium-format camera, further refined with the UltraCamLp in 2010 with a 92 MPixel image, in a radically-modified hardware configuration with several key features setting it apart from its competitors, including:

- All major functions incorporated in a single sensor head with optics and electronics, data storage and processing
- Use of solid state storage, easily changeable and lightweight

The UltraCamLp was introduced to address a range of small to medium projects, where maximum coverage is not the single most important aspect, and where a smaller footprint allowed organizations with smaller budgets and smaller planes to adopt and benefit from UltraCam technology.

A new generation of UltraCam carried the core design principles forward together with many innovations, introduced as the UltraCam Eagle in 2011. Its compact design belies a new level of sophistication in its enhanced “silent-board” electronics, tuned to sensors @ 5.2micron pixel size, yielding an industry-leading 72dB signal-to-noise ratio, a 20,010 pixel swath width and a 260MPixel frame. The Eagle is also the first in its class to offer a field-exchangeable lens system, with the option of 80 mm (standard) and 210mm (tele, for high altitude flights) focal length. The sensor head also embeds the UltraNav flight management and direct georeferencing system from Applanix. The result is a lighter and more space efficient end-to-end
aerial data acquisition solution that reduces external components to just the pilot and operator displays, thus augmenting system reliability by minimizing cables and connections.

With the addition of the Eagle, the UltraCam family of imaging systems offers the aerial survey organization a full range of operating and performance characteristics that address flexibility to adapt to differing project requirements and airspace restrictions.

It is a testament to the strength of the core UltraCam design that it has been carried forward across all successive commercial UltraCam aerial models. In addition, the design was also employed for the rapid development and deployment of the UltraCamG (“Giant”), customized to specifications for Microsoft’s Global Ortho Program and used exclusively by Microsoft’s flying partners for that program.

Today, no other vendor offers a more complete range of aerial imaging sensors, each offering world-class image quality together with sub-pixel photogrammetric accuracy.

5. ULTRAMAP: Hardware-leveraged Software

The primary challenge in the transition from film to digital imaging is in handling data collection in the air to match or exceed information content of film at viable flight conditions. But the real usability is measured in terms of throughput in production, from start to finish. It is the role of the UltraMap Workflow Software System to provide a powerful, seamless bridge from data acquisition to production of final mapping products. UltraMap is the perfect complement to software-leveraged hardware of the UltraCam, by exploiting the unique capabilities of UltraCam in the air to create an integrated and complete photogrammetric workflow (“hardware-leveraged software”). Examples of this include:

- Integrated Aerial Triangulation, incorporating UltraNav georeferencing information
- Monolithic Stitching and Monolithic Radiometry, providing consistent, superior geometric accuracy and image quality even in extremely challenging imaging conditions
- Model-based radiometric correction for haze and hotspots
- Highly-automated project-based color balancing over very large numbers of images, flights and dates
- Dense Matching algorithms leveraging highest UltraCam overlap and premier radiometric quality to give more robust results in
- Generation of seamless broad-area orthos with (virtually) no building artifacts, using point-cloud processing to eliminate the need for seamlines

UltraMap Version 3.0 supports the full workflow from raw imagery to final products: DSM, DTM, Ortho, or geo-referenced stereopairs for feature compilation. It supports distributed task processing at all stages, with automated load balancing to exploit all available processing power.
6. OPERABILITY

From the outset, the UltraCam was designed to be straightforward to use, with an intuitive, easy to understand User Interface that was modeled more on a point-and-click digital camera than a traditional piece of avionics hardware. This style of user interface has been maintained throughout multiple generations of operating software, though expanded significantly in functionality and performance. More importantly, during normal flights the UltraCam is driven automatically through integrated components such as the UltraNav flight management system developed in conjunction with Trimble Applanix, and the UltraMount stabilized mount from Somag. This means that manual interaction and operation are both kept to a minimum.

7. SUPPORTABILITY

The transition to digital imaging for an aerial mapping organization requires more than simply the replacement of a camera. All aspects of the operation must be reviewed with a new eye. Requirements, policies and procedures well understood for a film-based project require detailed consideration. Issues such as archiving policies, approaches to color balancing, and a myriad of other details, must be addressed anew. It is therefore critical to take a holistic approach to support, from initial orientation and training, to ongoing maintenance and service programs.

As the UltraCam installed base has grown, so has the support infrastructure. A third support center has been established in Singapore, joining the two existing centers: Graz, Austria and Boulder, Colorado. The centers incorporate full UltraCam calibration labs, allowing the ongoing support of local and regional markets through standard preventative maintenance programs. Each new UltraCam installation is managed by an implementation team which addresses all aspects of system delivery and operation, not simply hardware and software. The worldwide team consists of highly-trained specialists aligned with different elements of the Microsoft Photogrammetry group, supported by industrial-strength support tools such as Microsoft Dynamics NAV ERP (formerly Navision), which allows supply chain management, and Dynamics CRM for managing and tracking customer issues. Together, these resources mean that UltraCam customers can receive 24/7 support from product experts, that spare parts are adequately stocked, and that maintenance can be anticipated and planned for. Additional
programs support the UltraCam community, including regular user group meetings and webinars on new product releases. Microsoft’s core commitment to the customer experience is reflected in the breadth and depth of resources available through its support organization for UltraCam operators.

As part of this support program, the UltraCam product roadmap has always considered the upgrade path for existing customers. There are many UltraCamD’s still in normal operation, either in original configurations or upgraded, and all able to benefit from the more recent version of UltraMap software. Also common are organizations that operate different UltraCam models, each focusing on different project types, but working in a common workflow environment.

8. MICROSOFT

Since 2006, Vexcel Imaging GmbH has been operating as a division of Microsoft. Today it operates as the Microsoft Photogrammetry business division, as part of the Bing Imagery Technologies group.

Microsoft’s work with Vexcel Imaging GmbH and the aerial survey community has taken two broad forms. The first has leveraged UltraCam imaging capability for use with major programs such as Virtual Earth and Bing Maps. The second has been a commitment to strengthen resources for developing, manufacturing and supporting the UltraCam and UltraMap products, at the same time leveraging complementary technologies already available within Microsoft. It is not possible to completely separate these two initiatives: the end result is that both product development and product support are both strengthened, to the ultimate benefit of each UltraCam operator.

With the acquisition of Vexcel Imaging by Microsoft in 2006, the UltraCamD and UltraCamX had already been released into the market. As sales of the UltraCam began to grow a major initiative was undertaken by Microsoft, in the form of Virtual Earth, to capture high-resolution imagery of major urban areas across North America and Europe, and to partner with UltraCam operators for the data acquisition.

Partnerships with UltraCam operators in the Virtual Earth program under Microsoft led to the acquisition of high-overlap 15cm- and 30cm- GSD imagery of 900 urban population centers worldwide. During the period 2007-2009, roughly 600,000 km2 were imaged. Under this program, UltraCam operators were provided a prioritized task list, but given flexibility to incorporate these targets into their flight plans over a period of time. Working together on the Virtual Earth program provided real, tangible benefits to UltraCam operators, to the Microsoft Virtual Earth program itself, and to the UltraCam development team. As a customer of UltraCam aerial survey operators for the first time, Microsoft gained a true understanding of the issues relating to operations, image quality, and product delivery.

But this was simply a precursor to the next set of partnerships, implemented for the Bing Maps Global Ortho program, which set out a simple and aggressive target: to map the entire contiguous continental United States and 11 countries of Western Europe at a resolution of 30cm (12”), and to achieve this within 24 months. UltraCam flyers play a key role in this operation, providing 100% of the base imagery
for this project, using the UltraCam G ("Giant") specially designed and adapted to the specifications of the program. The UltraCamG collects a very large panchromatic image, flown to provide high-overlap in support of automated production techniques while maintaining very high image quality in the final color ortho product. This partnership between Microsoft Bing Imaging Technologies group and the flying community resulted in 7,000,000 sq.km. being flown during 2011. The project is slightly ahead of schedule to complete its initial mandate by June 2012. This program is arguably the most aggressive and comprehensive undertaken by the industry. As of early 2012, almost 10,000,000 sq.km. of UltraCam imagery has been collected, almost 9,000,000 sq.km. of product delivered internally, almost 8,000,000 sq.km. live on Bing Maps, and 7,295,000 sq.km. available from DigitalGlobe, where it is marketed as its Precision Aerial product.

One of the key aspects of Microsoft’s Global Ortho program is that it served as an industrial-scale stress test for UltraCam, one which has provided the most in-depth examination of any and all issues which impact each step of the UltraCam workflow from collection through final product delivery. Working closely with UltraCam operators, the feedback has been invaluable in refining current product offerings, developing new product specifications, and building industrial-strength support programs.

9. SUMMARY

Working together with Microsoft, Vexcel Imaging has addressed the challenges which faced the aerial mapping marketplace ten years ago. The vast majority of major aerial mapping programs are now undertaken using digital cameras and a fully-digital workflow.

UltraCam alone has built on core photogrammetric design principles meeting the following key performance characteristics:

- Simultaneous collection of panchromatic and four multispectral bands (co-registered to 0.1 pixel)
- Geometric integrity to 1 micron
- Captured dynamic range of almost 13 bits, translating into an industry-leading 7600 grey values of image DN, 14 bit A/D conversion, full 16 bit image processing workflow
- Framing rate of better than 2 seconds
- Transfer and storage of raw, uncompressed imagery
- Full control of exposure (shutter-speed, aperture) independent of groundspeed and flying height

Few aerial mapping companies have the luxury of undertaking projects from day to day, week-to-week, that are identical in application and nature. Therefore the typical UltraCam flyer has to satisfy requirements from a broad range of clients and for a diverse set of applications. UltraCam offers a
unique combination of highest-performance specifications for operations in the air, combined with an unparalleled workflow for downstream processing.

Today’s aerial survey business is changing at an increasingly rapid pace, driven by new technologies and a heightened expectation for the highest quality, accuracy and throughput performance in creating imagery and mapping products. The trend to consolidation within the industry is balanced by the addition of new companies and organizations focusing on emerging and innovative opportunities.

In this environment, it is not enough for a systems vendor simply to introduce a new product with impressive specifications. To be accepted by the marketplace and to maintain that success over time, it must repeatedly demonstrate expertise through rigorous product design, must listen to feedback from its customers to accelerate product innovations, and must constantly support and partner its customers in their operations. Since the introduction of the first UltraCam model in 2004 and every year since, Vexcel Imaging has demonstrated this.

Since 2006, operating as Microsoft, and working closely as part of the Bing Imaging Technologies group, these trends have continued, with an accelerated introduction of new products and further strengthening of customer support resources and tools.

The market has responded. Over the past ten years, the aerial survey marketplace has absorbed an estimated 450-500 wide-area metric imaging sensors, of which almost half are UltraCam. Many UltraCam operators have become leading regional, national, or international organizations, and several have captured over a million frames of imagery and are scaling their operations to a PetaByte (1PB=1000TB) level. A common sentiment expressed is that UltraCam has been the key element in growing their future clients and business. The vast majority of commercial organizations flying UltraCam have seen their business grow in new areas, and have been able to complete and deliver projects not otherwise feasible.

UltraCam, and the commitment of Microsoft Photogrammetry to the aerial survey community, continues to shape the future of aerial mapping.