

# The Promise of Softcopy Photogrammetry Revisited

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### ABSTRACT

Digital large format aerial cameras can produce as many images as a user pleases, and yet the costs of the imagery do not increase, in fact they decrease. This is a vast difference from traditional film-based photogrammetry where minimizing the number of film images was a basic tenet of the discipline, since a project's costs were directly proportional to the number of images needed to complete it. Minimizing costs no longer is defined by minimizing the number of images, but by minimizing the use of human labor hours. The entire economy of aerial imaging is changing with the transition to digital cameras and the full digital workflow. This will change the market's behavior, both on the side of the end-users of photogrammetrically collected data as well as on the side of photogrammetric organizations.

More images will be created per project, mapping repeat cycles will shorten, costs per project will decrease, new data products will emerge and the competitive cost structure in photogrammetric organizations will come under intense pressure.

### 1. INTRODUCTION

Innovation in photogrammetry is accelerating under the influence of innovation in computing. It took about 25 years for the analytical plotter to move from its initial inception in the mid-50s to full acceptance in photogrammetric practice by 1980, marked by the ISPRS Congress in Hamburg. It took 10 years for the softcopy photogrammetry approach from an initial demonstration in 1990 when the initial precision film scanners became available, to full acceptance by 2000, the time of the Amsterdam ISPRS Congress. That acceptance was caused by both the feasibility via computing innovations, as well as the reemergence of the orthophoto. Major photogrammetric functions continued to be based on film, such as aero-triangulation and manual stereo vector collection. By about 2000, the time of the ISPRS Congress in Amsterdam, nearly every photogrammetric organization had become a user of softcopy photogrammetry, but only for ortho photo production. A minority had abandoned all film-based procedures and had converted to a strictly softcopy approach for all phases of photogrammetric image analysis, increasing the AT-throughput from perhaps 4 images per hour to 10.

Only 4 years have passed since the initial announcement and demonstration of digital large format aerial cameras in 2000 and now their large-scale acceptance into photogrammetric practice at this time is happening. Today, numerous digital cameras are flying (Petrie, 2003). Only a mere 4 years after the initial announcement can we already see that new large format aerial cameras will no longer be relevant unless they produce digital imagery.

The reason for this rapid acceptance of digital cameras is the promise of a fully digital workflow with benefits in economy and with the advent of innovative data products (Leberl & Gruber, 2003; Gruber et al., 2003). This transition is more fundamental than all previous innovations, since it will shake up the field in many ways. We argue that the photogrammetric field will convert to be a special computer application, with no trace of film left in any work flows. Traditional value systems based in photo scales, number of photos, scanning resolutions, levels of automation will go away, to be replaced by pixels, file sizes, archives and catalogs, the internet and immersive uses of 3-dimensional spatial data.

We want to examine the current situation and visit the status of softcopy photogrammetry in light of the advent of large format digital aerial cameras, progress in computing, fully automated procedures for AT, DEM and orthophoto generation, and the emergence of new types of terrain and GIS data products.

### 2. SOFTCOPY EVOLUTION

#### 2.1 Definition

Digital or softcopy photogrammetry designates the use of digital images for photogrammetric procedures and products. The beginning of this new technology depended on the availability of digital images, and these in turn required the advent of precision film scanning systems. Scanning film images leaves the image acquisition unchanged, and the traditional rules remained applicable to aerial photogrammetry since its early days 100 years ago.

Generally we can separate softcopy photogrammetry functions into categories:

- Film scanning;
- Aerial triangulation;
- Digital terrain elevation “scanning”;
- Orthophoto generation ;
- 3-dimensional vector data stereo collection as input to a GIS

Of course there exist various special functions, for example when existing data need to get updated, or when pre-existing DEM-data are used for orthophoto production. Orthophotos may be the basis for 2D or even 3D vector collection using a mono-plotting approach, avoiding the use of overlapping stereo images.

## 2.2 Practical Applications

It may be worth noting at this time that the functions of first acquiring aerial images and then processing them into data products are conceptually separate, with a simple transfer of film images or of scanned image files. Therefore it is not uncommon to find that one organization produces images, another one processes these.

Orthophoto production has been totally taken over by a softcopy approach. In fact, no orthophotos would be produced today had softcopy not been feasible. The function of digital terrain elevation scanning, if done from stereo images, has to some degree been converted to the softcopy domain. Yet, analytical or even analog plotters still are the workhorses of stereo-photogrammetric data processing to this day. All functions related to a human’s visual stereo impression are to a great extent not performed with digital images. Producing a DEM may therefore be based on manual stereo observations, since the opinion exists that an automated creation of a DEM from scanned film requires much manual error removal so that it is not advantageous to go digital.

## 2.3 Automation and Instant Gratification: Laser Scanning, Direct Geopositioning

The inability of full automation of photogrammetric procedures has created a need for systems that determine the exterior orientation of each image automatically by means of GPS and IMU-measurements. This in essence replaces the function of the aerial triangulation (AT). And the inability of a fully automated DEM-creation has caused a need for direct terrain elevation measurements by means of laser scanners. Both systems have reduced the need for traditional photogrammetric core competencies. Yet, to take full advantage of them, associated images need to be digital. Softcopy photogrammetry has therefore developed a branch that merges direct geopositioning observations with pixels to project them into orthophotos, given an independently produced DEM. And the laser scanner observations, representing an externally available DEM, get merged with digital images to produce an instant orthophoto. Both the direct geopositioning and the laser scanners reduce the need for manual labor and therefore affect costs, and they reduce the time it takes to produce a DEM and orthophoto, thereby improving the competitive position of a firm.

## 2.4 The Advent of Digital Imaging

With digital cameras, film no longer exists and the options of processing images in an analog or analytical plotter go away.

Therefore softcopy photogrammetry takes over all photogrammetric functions. In fact, one important new function gets added that did not exist in the world of film-based photogrammetry:

- image archiving and cataloguing.

That function was previously in the hands of the photo lab and film archive. With the advent of digital cameras, photo labs become obsolete, and so do film archives.

The capabilities of softcopy photogrammetric software gets stressed: while previously, softcopy systems needed to process what otherwise would be processed on analytical or analog devices, now the data quantities may increase considerably, perhaps by a factor of 5. While traditional film photogrammetry may have each object point on only 2 images, a digital system can increase the at no extra cost for the images to 10. The traditional forward-/side-lap percentages at 60/20 can and will be increased to 80/60. This affects of course the data quantities and requires the acceptance and implementation of advances in computing. Moore’s law is a welcome factor that promises that over the next 10 years, computing will improve its price-performance ratio by a factor 100. Image storage, retrieval, transmission, processing and information extraction are currently feasible with such increased data rates, and this feasibility will improve dramatically over the coming years.

## 3. DIGITAL VERSUS FILM CAMERAS

### Superior Economy

- No consumables such as film, processing
- No scanning
- No cost color and color IR
- No cost of duplication
- Reduced manual labor

### Superior Image Quality

- Note: 12 bits/pixel; No grain noise
- Better matching accuracy (2.5 x film)
  - More flying days in marginal weather
  - Better interpretability
  - Better success in automated procedures

### Increased Redundancy in All Measurements

- Note: Higher forward overlaps at no extra costs
- Better success in automated procedures
  - Superior automated DEM generation
  - Fewer occluded areas in urban projects

### Superior geometric accuracy

- No image shrinking or other deformations
- Inner orientation is system-inherently available
- Identical duplicates
- Absence of grain results in higher accuracy
- Radiometric range improves accuracy

### Superior Work Flow

- In-flight quality control
- Automation with less manual intervention
- Improved manual interpretability (RGB&IR)
- No more film management
- Intra-/Internet-enabled archiving and cataloging
- Camera maintenance via Internet

Figure 1: List of advantages of digital sensing over film cameras in photogrammetry

Figure 1 summarizes the advantages of digital sensing over film images in photogrammetry. The advantages are grouped into 5 categories. Of course they are all interdependent. Reduced manual labor affects the economy, yet it also represents an advantage in the workflow. An increase in accuracy, while of value all by itself, also affects the economy.

A very important factor is the ability to enjoy a no-cost increase of image overlaps. This is denoted as “increased redundancy”. This factor is the least-often discussed when reviewing the transition to digital cameras, yet it is considered by us to be the most fundamental. Photogrammetry has been relying on two rays to intersect a 3-dimensional point, basically without any redundancy. If a ray from one image is in error, then the point position cannot be measured at all, a deficiency of stereo-photogrammetry since its inception. Insufficient redundancy is the major reason that automatically created DEMs using stereo matching of scanned film images have significant errors and miss data, and occlusions due to a lack of redundancy are the major limitation of orthophoto products.

The transition from minimizing the number of film photos to maximizing the robustness of automation by a free definition of the number of images can be a major shift in the photogrammetric value system, and can be called a „paradigm shift“.

#### 4. AUTOMATION OPPORTUNITIES

##### 4.1 Multi-Ray Matching

Increasing the redundancy leads to a change from 2-image stereo operations to multi-image, multi-ray matching. Aerial triangulation tie points get collected from 10 images rather than 3 or 6 in model and strip overlaps, leading to as much tighter fit and more robust solution. DEM matching is with 10 images versus 2, and producing an over-determined solution where previously there was no over-determination. Orthophoto texture derives also from 10 versus only 2 inputs, and the need to carefully delineate the seam between adjacent photo sources in one single orthophoto-mosaic goes away.

All this is simply from a transition to the 80/60 overlaps versus the traditional 60/20. The robustness of matching increases. Dissimilarities between adjacent images get smaller and matching errors are less likely. As a result, AT and DEM-creation become fully automated, and the orthophoto will be “true” with no extra effort.

Can we hope to soon achieve softcopy direct geopositioning and a softcopy terrain scanning function? Figure 2 presents an automatically created DEM from 4 images. No manual work was applied, yet there are no spikes nor holes visible in this DEM.

##### 4.2 Use of Multiple Color Bands

Color had been a low priority issue in traditional photogrammetry. Only the advent of the orthophoto has made color an important factor, but all geometric processing is color- neutral.

Now we have a no-cost, free ability to increase the use of color bands, starting out with at least red-green-blue-infrared. This will improve the ability of automatically interpreting the contents of the image. Image classification promises to become a routine operation in the photogrammetric work flow to support all its operations, be it for AT, DEMs or vector collection.

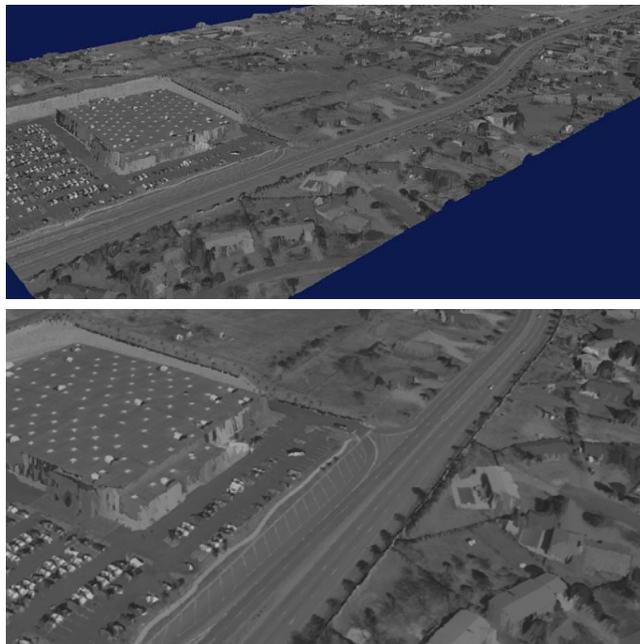


Figure 2: DEM created automatically by multi-ray matching. Each terrain point is in at least 4 images. Above: 3 million triangles & image texture of an area in Colorado Springs. Below: Detail with business building, highway and parking lot with cars. Note the curved sidewalk along the parking lot.

DIGITAL CAMERA ECONOMY, W/O PHOTOGRAMMETRY	
Item	US\$
Camera annual depreciation	80,000
Camera annual maintenance	40,000
Camera miscellaneous (e.g. insurance)	10,000
Level-2 and 3 post processing depreciation	4,000
Archiving tapes, 60,000 digital images	2,000
Archiving & cataloging system, depreciation	30,000
Flight operations, extra for 60% sidelap flying	50,000
SUM	216,000
<b>Per each of 60,000 digital images</b>	<b>4</b>
<b>Per each of 20,000 (film-equivalent) images</b>	<b>11</b>

FILM CAMERA ECONOMY WITHOUT PHOTOGRAMMETRY	
Item	US\$
Camera annual depreciation	TBD
Camera annual maintenance	5,000
Camera miscellaneous (calibration)	5,000
Film purchases, 20,000 images annually	80,000
Photo processing, 20,000 images annually	60,000
Scanning, 20,000 images annually	200,000
Film archive operating costs, annually	1,500
Digital archive operating costs, annually	1,500
SUM	353,000
<b>Per each of 20,000 film images</b>	<b>18</b>

Figure 3: Direct costs creating single film (below) & single digital image (above), based on annually 20,000 film and an equivalent 20,000 digital images (when in fact 60,000 digital images get produced to cover the same area). Digital coverage not only comes for less money than film, it also comes at much higher overlap/redundancy. All costs assumed to be typical for a mix of European and US operations, over all scales. Note that of course costs may vary greatly with scale, area and organization. Basic flying costs excluded.

### 4.3 Avoidance of Occlusions

Dissimilarities between overlapping images are most distinct where vertical terrain objects occlude adjacent objects. One of the attractions of laser scanner data is their ability to cover areas otherwise hidden in stereo models. Sufficient image redundancy can achieve a comparable avoidance of occlusions.

## 5. THE “KILLER ADVANTAGE” -- ECONOMY

The cost of a digital camera operation is defined by the annual depreciation of the camera, the survey plane, crew and flight environment. It is not, however, defined in any way by the number

of mages being created per year. When compared to film imaging, there exist only the fixed costs of the digital system, no additional costs per image made (with the exception of additional flying time if 60% side-laps are used).The more images are being made, the less are the costs per image. Plane, crew and flight support systems are considered the same for film and digital cameras, except for extra fuel and extra use of the survey plane if side-laps get increased from 20% to 60%. What differs is the cost for consumables (film, photo processing), certain labor such as scanning and film management, maintaining a photo lab and a film archive.

Figure 3 attempts to compare the economy of a digital versus a film-based flying operation. Of course the numbers are rough estimates and will vary for specific situations. The cost of flying 60% side-laps may vary greatly dependent on the cost structure of a flying operation. The costs of an archival and cataloguing system could be charged to the photogrammetric processing rather than the flying operation. Generally, however, one will quickly see that digital camera operations reduce costs, yet produce a higher value input data set.

Figure 4 compares the costs of photogrammetric processing into map/GIS data products such as DEMs, orthophotos and 3D vector data. Here the numbers aim at comparing “apples with apples”, thus the same ground areas and the same data products, once produced by a current organization using both digital data from scanned film plus film data on analytical/analog plotters, and in the other case a radically modern organization with a fully digital work flow. Figure 4 assumes that all of the annually produced 20,000 film images get converted to orthophotos, and also get converted to 3D vector maps/GIS-input. With an annual cost for a human operator at \$ 40,000 the manual labor is the overwhelming cost factor, and depreciation for equipment use is but a minor expense. The 80%/60% overlaps in the digital domain will produce an overwhelming advantage in automation, and the dual analog/softcopy work flow can be abandoned, leading to significant cost reductions.

The conclusions from Figures 3 and 4 are that there should be a cost reduction by a factor of roughly 2 for both the acquisition as well as processing of digital images into deliverable data products.

## 6. MARKET CHANGES?

Indications are that the following may happen:

- The split into image acquisition specialists and photogrammetric processing specialists may break down. Processing collected digital images into deliverable images (the post-processing need) makes it logical that level 4+ processing gets merged in with the production of color images by post processing. Also automation will make it illogical to separate image acquisition from image analysis.
- The end users may want to consume part of the cost savings and are going to pay less per square kilometer and data product. Since mapping budgets will not shrink, there will be more images and more frequent re-mapping,.
- The concern for quality may be replaced by the concern for rapid response and lower costs, leading to a reduced concern for quality.
- New data products will emerge that better model the 3-dimensionality of the human habitat, and that take full advantage of emerging mixed reality, immersive human-computer interaction and wearable computing devices.

DIGITAL CAMERA PHOTOGRAMMETRIC ECONOMY	
Item	US\$
Level 4+ processing depreciation	Incl. in archiving
Depreciation for 6 manual editing work stations	6,000
Manual editing, 1 hr/ image <sup>1</sup>	500,000
Depreciation for 13 stereo work stations, 2 shifts	6,000
Stereo plotting, 2 hr/image <sup>1</sup>	1,000,000
SUM	1,500,000
<b>Per each of 20,000 film-equivalent images</b>	<b>75</b>

FILM CAMERA PHOTOGRAMMETRIC ECONOMY	
Item	US\$
Depreciation of 7 analytical plotters, 3 shifts	70,000
Depreciation of 6 softcopy work stations	6,000
Manual editing, 2 hr/image <sup>1, 2</sup>	1,000,000
Stereo plotting, 4 hr/image <sup>1, 2</sup>	2,000,000
SUM	3,000,000
<b>Per each of 20,000 film images</b>	<b>150</b>

Figure 4: Comparing the costs of converting 20,000 film images and the equivalent number of digital images into photogrammetric products. It is assumed that all 20,000 images get processed into DEMs, ortho photos and 3D vectors. Note that there will be 60,000 digital images covering the area of 20,000 film images. The 60,000 digital images are input into the automated procedures. For the manual work on the digital images, only the “best” stereo overlaps are being used. The manual work is proportional to surface area, not number of images, and therefore is computed on the basis of the film images, to compare “apples with apples”. Savings at \$ 75/image.

In Figure 3 on film cameras, no value was attached to the depreciation of film cameras. However, if no new film cameras get sold, then the value of film cameras goes to zero, and any current book value would need to get written off. Similarly, any residual

<sup>1</sup> Assuming an annual labor cost of \$ 40,000, and 1600 labor hours per year, addressing 20,000 “entities”.

<sup>2</sup> Manual work for AT, DEM preparation, orthophoto creation and vector collection.

book value in a photo lab and in analytical/analog plotters would have to be set to zero,

Generally the transition to digital imaging and to a totally digital workflow offers opportunities to reduce costs, in particular in the conversion of images to data products (the level 4+ process). It will be this ability of photogrammetric operations to automate its procedures on the basis of an unlimited increase in the redundancy of the source data that will separate the survivors from those who may not survive the emerging paradigm shift.

## 7. CONCLUSIONS

As is typical of shifts in the prevailing rules of an established discipline (its "paradigm"), changes affect every participant. Examples exist in abundance of disciplines that did get totally changed with the advent of computing innovations (examples: printing industry, telecommunications, watch making....). Many players may no longer continue in the field, others may enter with a fresh approach.

The skill set needed to succeed in the future "New Photogrammetry" is shifting rapidly to computing and computer network operations. Software, software operations, networks of inexpensive computers, large disks and tape arrays, the web and "ubiquitous computing" all dictate who will succeed in the "New Photogrammetry", where the entire work flow is digital, automation has taken over many previously manual tasks and film has disappeared.

We expect that the costs for image acquisition will be cut in half by the transition to digital sensing. We also assume that the costs of photogrammetric processing will be cut at least in half by abandoning the analog/analytical work flows and transiting to fully digital procedures and products. This assumption is based on the expectation that automation can eliminate 50% (or more) of current manual labor. In some phases such as AT, DEM and orthos, the labor costs may be cut to a mere 10<sup>th</sup> of they were previously. And the age-old paradigm of "minimizing the number of expensive film images" will get abandoned. Instead, success will depend on an organizations' ability to set up fully automated procedures using a free choice of no-cost digital source data.

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