138

Digital Photogrammetric Plotting Techniques

by

Franz W. Leberl

VEXCEL Corporation
2477 55th Street
Boulder, Colorado USA 80301

ABSTRACT

The window of opportunity for pixel-based digital photogrammetry is open. Digital image processing boards, digital sensors, digital low-cost high-performance computing all combine as the technological base on which the *software* needs to grow to accomplish the transition from analytical (coordinate processing) to digital (pixel processing) photogrammetry. The acceptance of this technology will depend on finding proper tools to integrate film imagery with this technology, and in achieving significant cost/benefit advantages in the information extraction and photogrammetric plotting.

1. ANALOG, ANALYTICAL, DIGITAL

We commonly differentiate between analog, analytical and digital photogrammetry (Figure 1).

ANALOG	ANALYTICAL	DIGITAL
MECHANICAL	COMPUTER FOR COORDINATES ONLY	COMPUTER FOR PIXELS AND COORDINATES
OPTICAL ANALOGONS		

Figure 1: TYPES OF PHOTOGRAMMETRY

Photogrammetry is defined in Figure 2 as a technology, and in Figure 3 it is defined by its products: maps, positions, rectified images. Analog photogrammetry models the imaging processing by mechanical, electrical or optical analogons. Typical manifestations are the many widely used stereo-plotting instruments that convert a pair of photographs into a map manuscript. To this day, such technology is still the "work-horse" of practical photogrammetry, while it is technologically entirely obsolete.

"The acquisition and processing of information about objects and processes by means of photographic images. In the past this included shape, size, position. Today it also includes identification, classification."

Paraphrased from K. Schwidefsky, F. Ackermann (1976)

"Photogrammetry is the art, science and technology of obtaining reliable information about physcial objects and the environment through processes or recording, measuring and interpreting photographic images and patterns of electro-magnetic radiant energy and ortho phenomena"

Quote from Manual of Photogrammetry, 4th Edition (1980)

FIGURE 2: WHAT IS PHOTOGRAMMETRY – DEFINITION IN TEXTBOOKS ON PHOTOGRAMMETRY

FILM PHOTOGRAPHY ---> MAPS
FILM PHOTOGRAPHY ---> POSITIONS AND SIZE OF OBJECTS
FILM PHOTOGRAPHY ---> ORTHO- RECTIFIED FILM IMAGERY

FIGURE 3: WHAT IS PHOTOGRAMMETRY -- DEFINITION BY PRODUCTS

Analytical photogrammetry employs the computer for one purpose only: the processing of spatial coordinates. Data sources are still in the form of analog film and viewing of film is by optical devices. However, all coordinate relationships are now modelled by computer software rather than optical or mechanical analogons of projection rays. Clearly, analytical procedures in photogrammetry, and the terminology, were introduced first in some specialized process segments, particularly aerotriangulation or point field densification, and have become routine tools for photogrammetric data generation since about 1970.

In industrialized environments, the so-called analytical plotter has taken over from analog machines as the work-horse of photogrammetry. In this plotter, all coordinate relationships (between world coordinates XYZ and image coordinates x'y' (left), x"y" (right) are implemented via microprocessors (Helava, 1958).

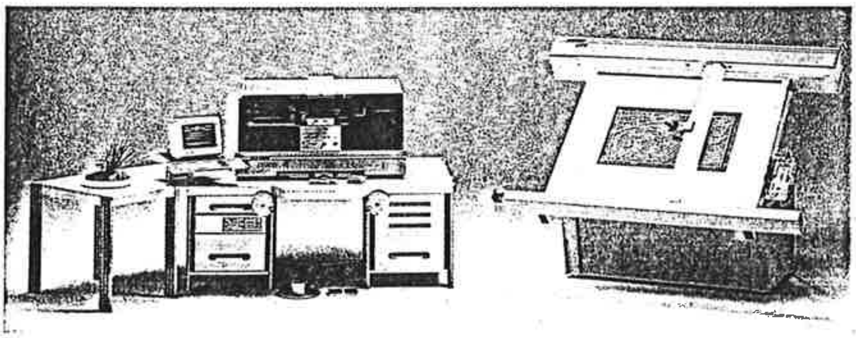

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FIGURE 4: EXAMPLE OF ANALYTICAL PLOTTER: ALL COORDINATE RELATIONSHIPS ARE IMPLEMENTED DIGITALLY, THE IMAGE CONTENT IS ON FILM

Digital photogrammetry does away with film and optical viewing. Instead it operates with pixel arrays and video display monitors. Both the coordinates and thematic image content are subject to computer processing. Mechanical precision is replaced by counting pixels.

No practical implementation of digital photogrammetry has yet displaced analytical, commercial photogrammetry (with the exception of specialized scenarios, for example in the defense area). The following will outline reasons why, and will present recipes to guide digital photogrammetry to its victory over soon-to-be obsolete analytical technology.

2. WHY DIGITAL PHOTOGRAMMETRY?

Figure 5 summarizes the expectations that exist in the field for the benefits to be derived from displacing analytical by digital photogrammetry. Most prominent are "automation", "cost" and "training".

Increased Throughput at Reduced Cost
Automation or Computer-Support in Manual Work
Less Training Since More Computer Support
Sensor Independence
Use of Data vs Creation of Data
Ease of Merging Various Data Types ---Vectors and Raster Data

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FIGURE 5: ADVANTAGES OF DIGITAL PHOTOGRAMMETRIC SYSTEMS

Automation, of course, is expected to increase throughput. But it is also hoped to de-mystify photogrammetry and make it accessible to non-photogrammetric scientists and engineers *without* the need for extensive training.

Often the use of images to create data about a phenomenon or object is divorced from the use of the data for decision making. Common examples can be found in all levels of government or in the Earth sciences: planners use maps, but do not create them, nor do they keep them updated. Digital photogrammetry promises to reduce the sophistication of the appearance of photogrammetry to that of TV-technology with its ease of use. Photogrammetry does not need to remain the preserve of highly trained specialists.

Finally, the digital techniques enforce a level of standardization in hardware and computer technology that promises to provide great ease of merging many requirements into a computer workstation:

- map data in vector form (GIS);
- various sensors (radar, photos, electro-optical scanners);
- various processing techniques (single images, stereo, shape from shading, manual and correlation-type measurements, classification, etc.).

Digital photogrammetry may thus appear to be characterized by a role as equalizer,with one workstation being capable to address many problems for which previously a range of hardware had to be used. Figure 6 further suggests that the opportunity exists to accomplish, by machine support, a transition from highly specialized knowledge requirements to a type of "*photogrammetry for the man-in-the-street*".

Analog/Analytical Photogrammetry --	Mysterious and Complex
Digital Technology --	"Volks" - Photogrammetry (For Photogrammetry-naive Users) Equalizer (Many Sensors, Many Data Types)

FIGURE 6: FROM CONVENTIONAL TO DIGITAL PHOTOGRAMMETRY

3. WHERE IS DIGITAL PHOTOGRAMMETRY TODAY?

Digital photogrammetry can be characterized by three components:

sensors,
workstations,
procedures.

All three have limitations that need to be overcome to realize the promise of the technology.

3.1 Sensors

Current digital sensors do not produce images that can compete with film cameras for the main concerns of photogrammetry: accuracy and geometric resolution. Digital sensors exist in space due to the obvious advantages of telemetering the data, and due to experimentation with spectral resolution. But geometic resolution is vastly insufficient to accomplish what the greatest part of photogrammetric applications serve: large scale mapping at ground resolutions of 10 cms to 1 m.

The airborne digital sensors of use today are radar imaging devices and experimental multi-spectral scanners. These will only be able to compete with film photography if:

the resolution increases to the 1 m range or better, while maintaining a wide field-of-view (producing 20,000 pixel swaths);

if the geometric accuracy of the extracted information improves consistently into the sub-pixel range in all three coordinates X, Y, Z.

This is entirely feasible, but the relevant technologies have not (yet) matured, let alone been announced for practical application. Digital sensing currently only is fully applicable if emphasis is not on accuracy or resolution but on thematic issues: (satellite remote sensing), or on real-time applications, such as in industrial robotics vision (Gruen, 1989).

For digital photogrammetry, then, one needs to prepare for the continued use of film images. This puts great emphasis on the conversion of film into the computer, or scanning (Figure 7). We need to expect that digital photogrammetry will not displace analytical technology *without* an appropriate breakthrough in the ability to *convert* film images into pixel arrays.

Film:	Typical for Aerial Photography
Digital Images:	Typical from Satellites, Sometimes from Aircraft Increasingly in "Close Range Real-Time" Situations
Critical Issue:	Convert Film Imagery to Pixel Arrays -- Scanning

FIGURE 7: PHOTOGRAMMETRIC SOURCE MATERIALS

Film scanning technology is therefore of great importance to the success of digital photogrammetry systems. This is one of the drivers behind recent innovations in filmscanners (Leberl et al, 1987).

3.2 Workstations

Not surprisingly, there is considerable activity in the design of digital image processing work stations for photogrammetry. Typically such developments are distinguished by:

stereo image displays;
an interface to geographic information systems.

Vendor	Model	Comments
Kern/Wild	DSP-1	Split screen with sterescope
MS-2I	Traster T10N	Stereo-Spot
Topcon-Japan	Imagenet	Ophthalmological. A mapping system was shown at the ISPRS congress in Tokyo in 1988
I²S	Orthophoto Workstation	To be introduced
Autometric	Pegasus	Configured from COTS (Commerical Off The Shelf) Components
Helava Associates, Inc.	HAI-500	Tektronix stereo monitor
Context Vision	Context Mapper	To be introduced

FIGURE 8: DIGITAL PHOTOGRAMMETRIC SYSTEMS BY COMMERCIAL VENDORS. THIS EXCLUDES NON-STEREOSYSTEMS FOR MAP PING WHICH MAY INCLUDE ELEVATION EXTRACTION (E.G., INTERGRAPH-TIGRIS, ERDAS, IMAGE DATA, GEOSPECTRA, STX, ETC.)

Figure 8 lists some offerings by commercial vendors. Closer inspection reveals that many of the offerings are merely prototypes not yet available for commercial delivery, and miss a systems-view to include input, data creation, sensor models, and procedures in a manner that offers clear advantages over analytical photogrammetry.

3.3 Procedures

At the heart of a successful transition to digital techniques we find, of course, the availability of procedures that create clear advantages. We see three components:

elevation data extraction;
planimetric data extraction;
image ortho-rectification.

A fourth element would be project administration. A fifth element the image "set-up" in the form of aerial triangulation and stereo model creation. However, routine photogrammetric resources are expended mostly on the collection of planimetric data; secondly on elevation data; thirdly on image rectification. Stereo-model set-up and photoblock computations occupy only the smallest segment of the photogrammetric resource pool (see Figures 9 and 10).

Automation and throughput increases by digital techniques have been suggested in the area of elevation measurements and ortho-rectification. Systems for digital correlation have been described as they apply to digital source images (Hahn and Foerstner, 1988; Mueller et al, 1988). However, these suggestions derive from research reports based on laboratory settings. There exist no commercially available procedures for automated elevation measurements that would represent an improvement over those performed manually on an analytical plotter.

Image geo-coding or ortho-rectification has been automated in computer-controlled analytical (i.e. film-based optical) ortho-photosystems. Recent announcements of digital orthophotos based on film scanning therefore do not seem to represent a throughput advantage (Hood et al, 1989).

Automation of the aerotriangulation or stereo-model set-up is being offered commercially (Helava and Seymour, 1987). While it does not solve a throughput or cost issue of analytical photogrammetry, such automation does reduce some resource constraints on trained personnel skilled in the intricacies of photogrammetric image block methods.

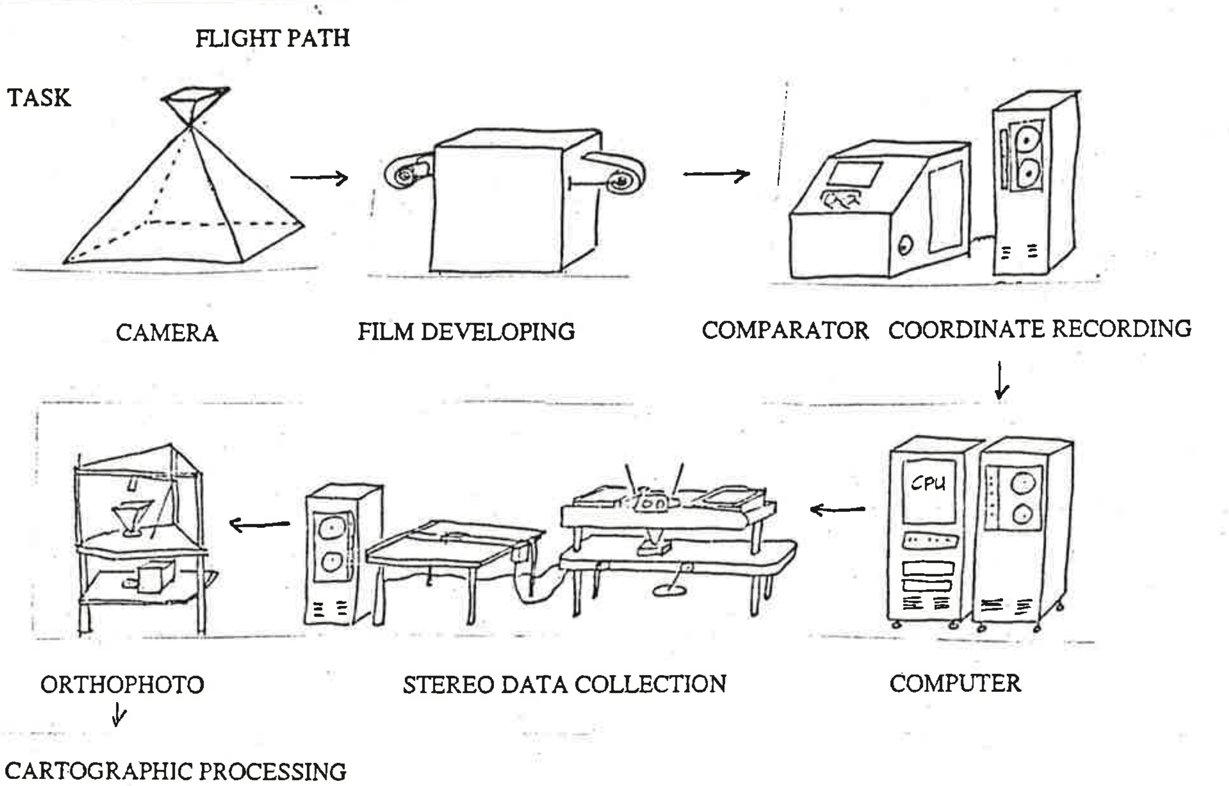

FIGURE 9: TYPICAL PHOTOGRAMMETRIC PROCESS

It is evident from Figure 10 that the greatest benefit from automated digital methods would be derived from an ability to extract planimetric information. However, this technology is least developed among those currently being studied for digital photogrammetry.

Function	Effort per Photo or Photo Pair	Comment
Aerial Triangulation	0.5 to 1 hr.	0.5 hrs on analytical plotter
Stereo Model Set-Up	0.2 to 1 hr.	0.2 hrs. on analytical plotter
Plotting of Height	3 hrs. to 6 hrs.	Depends on terrain type
Plotting of Planimetry	6 hrs to 40 hrs.	Rural vs. urban
Orthorectification	1 hr. to 2 hrs.	Requires digital elevation
Formatting, delivery	1 hr.	Magnetic tape
Preparation, management	0.5 hrs. to 1 hr.	Naming, materials, index sheets, etc.

FIGURE 10: EFFORT SPENT ON VARIOUS PHASES OF THE PHOTOGRAMMETRIC PROCESS (FROM VARIOUS SOURCES, INCLUDING SCHWIDEWSKY, ACKERMANN (1976) AND VISSER (1980)).

3.4 Other Considerations

While a clear throughput advantage would be the strongest element to convince users of the benefits of digital photogrammetry, there are sufficient other advantages to support its rapid acceptance. Among these we believe the most prominent are:

- cost of hardware (computer, image processing boards, displays);
- ease of combining image pixel arrays and vector map data.

However, there remain several key issues that need to be resolved before these advantages come to bear. Those address availability of:

- film scanning in a cost-effective manner;
- stereo displays of color images;
- basic commercial-grade software for those tasks that make the digital system functionally at least equal to the analytical plotter.

Resolution of these issues does not require any new technology but only the commerical-grade integration of laboratory-type prototype capabilities into a robust system.

4. STEREO VISUALIZATION - VIEWING OF DIGITAL PIXEL ARRAYS

One hundred years of improving skills of optical designers have led to high quality binocular viewing systems in photogrammetric stereo instruments. This has combined with high accuracy positioning systems to move film carriers (or stereo measuring marks) resulting in high precision equipment. Digital systems need to compute with the convenience of stereo-viewing and accuracy of setting a *floating dot* onto the object in the stereoscopic model. Doubts that a similar convenience and accuracy can be achieved by digital displays need to be addressed.

Pointing accuracies in digital stereo-images need to be assessed and compared to the equivalent accuracies in film. Pixel size versus film resolution are at issue, as are concerns about the accuracy of parallax detection. Stereo cursor movements on a stereo display monitor may have to be supported by *tracking stereo correlation* software to achieve the best accuracy. This may also relax the need for highly trained stereo operators since accuracy would not be determined by manual setting of the measuring work on the terrain or object surface. Instead the manual setting is merely input to correlation-based refinement software.

Again, therefore, digital photogrammetry shifts the burden of performance from the skills of the user to the quality of the software.

5. SYSTEM OVERVIEW

Figures 11 and 12 review a desirable configuration for a digital photogrammetry hardware and software system. Note that no hardware component of such a system is photogrammetry-specific. Therefore, recurring hardware cost is not related to the (limited) number of photogrammetric systems the industry could absorb, but the much larger number of component sytems the computer industry at large is absorbing. Software, on the other side, is specifically photogrammetric: its cost is thus a function of the size of the photogrammetric market.

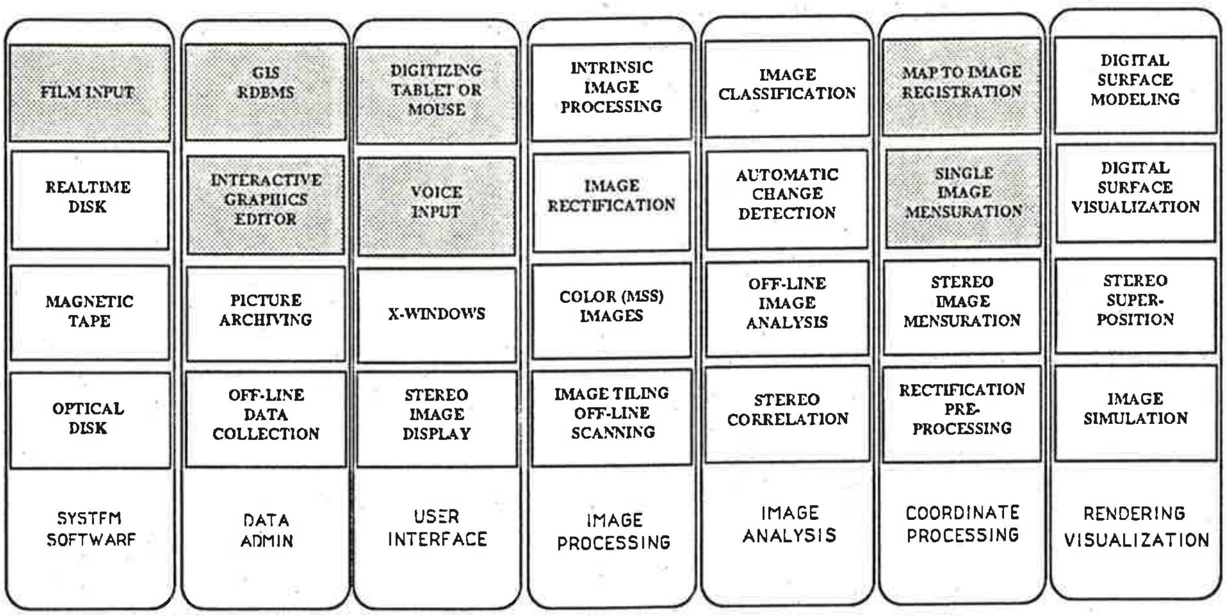

FIGURE 11: SOFTCOPY PHOTOGRAMMETRY SOFTWARE (NEARLY SENSOR INDEPENDENT, VARIOUS IMAGE SENSORS POSSIBLE)

Figures 11 and 12 are self-explanatory. While there is the expectation that little is to be argued about the needs for hardware, there is large flexibility in the software area. Figure 12 is therefore merely an example for a wish list of functionality in a digital photogrammetry workstation.

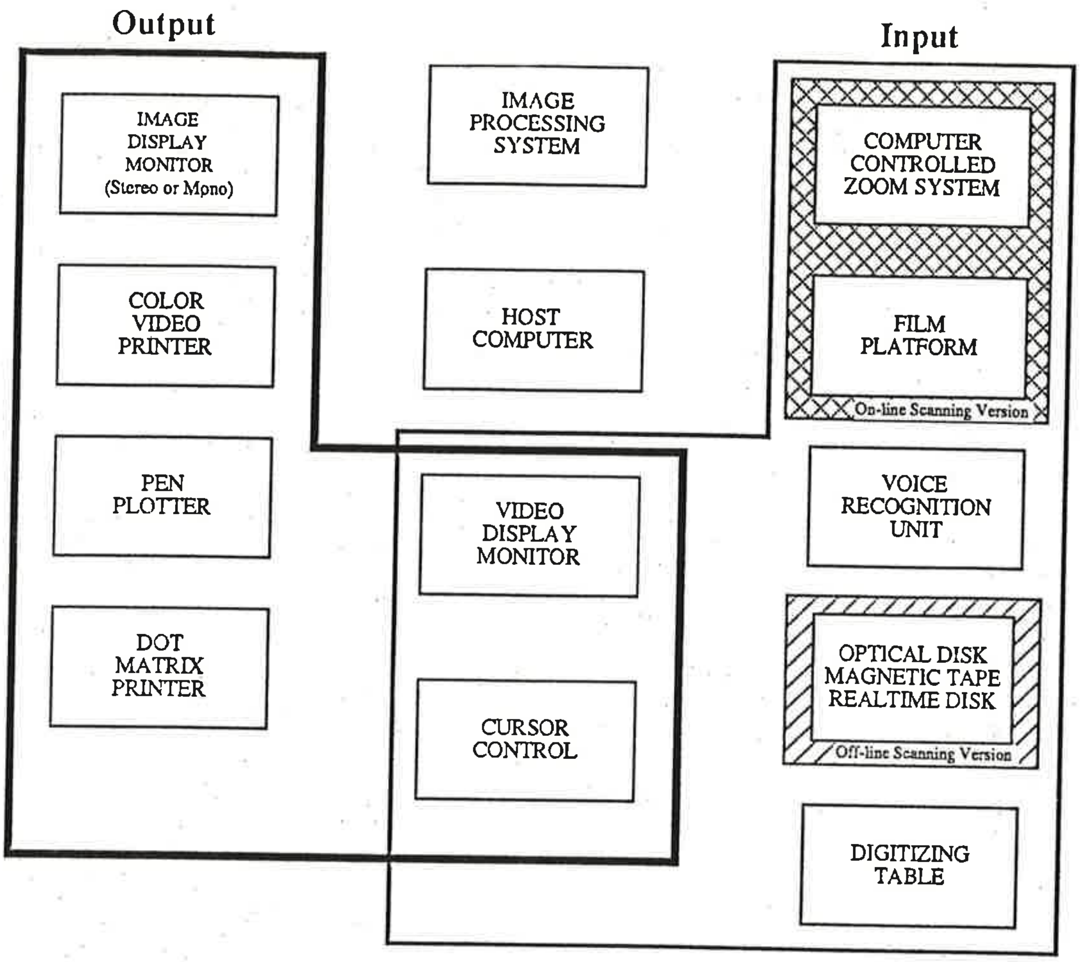

FIGURE 12: HARDWARE FOR A DIGITAL PHOTOGRAMMETRY WORKSTATION.

6. CONCLUSION

No technological breakthroughs, not even any significant innovations, are in the way of accepting digital photogrammetric systems. The paper makes the argument that successful systems are feasible if some ground rules are observed:

- package existing technology into an integrated system;
- implement existing software concepts into a competitive, commercial-grade deliverable configuration;
- provide functionability that at least equals the accuracy and throughput of current analytical photogrammetry;
- implement a system that includes the ability to use film sources in a cost-competitive manner.

With a resulting digital photogrammetry workstation the product life cycle of analytical photogrammetric system will end.

This puts an interesting perspective on the history of photogrammetry. Photogrammetry was originally conceived to circumvent the computational burdens put on surveyors to develop maps: instruments were analog computers to avoid numerical work. Digital photogrammetry introduces numerial operation to avoid analog computation (Figure 13).

1864:	Laussedat
	Measuring from images === Iconometry
1855:	Kersten, Meydenbauer
	Measuring from images === Photogrammetry
1930:	Otto von Gruber
	"He who computes much thinks little"
1976:	Schwidefsky/Ackermann
	"It is obvious that the technology and solution of photogrammetric problems transfers entirely into computer science and numerical mathematics."

FIGURE 13: PHOTOGRAMMETRY THEN AND TODAY

Even the word "photogrammetry" is to be questioned in the digital era: data sources increasingly consist of a range of image types, not just photography. Therefore, the french proposal by A. Laussedat in 1864 to name this emerging technology "iconometry" looks more relevant now and one may almost regret that the German geographer Kersten (1855) and architect Mydenbauer displaced the name by their word "photogrammetry."

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