HISTORY OF PHOTOGRAMMETRY

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EARLY DEVELOPMENTS

Although photogrammetry employs photographs (or digital imagery today) for measurements, the concepts go back into history even earlier. Leonardo da Vinci in 1492 began working with perspective and central projections with his invention of the Magic Lantern [Gruner, 1977]. Other scientists continued this work mathematically. Albrecht Duerer, in 1525, using the laws of perspective, created an instrument that could be used to create a true perspective drawing [Gruner, 1977]. In 1759, Johan Heinrich Lambert, in a treatise "Perspectiva Liber" (The Free Perspective), developed the mathematical principles of a perspective image using space resection to find a point in space from which a picture is made.

The first photograph was obtained by Joseph Nicephone Niépce (1765-1833). The positive image Niépce required an eight-hour exposure. In 1837, Jacques Mandé Daguerre obtained the first "practical" photograph using a process called the Daguerreotype. Around 1840, the French geodesist Dominique François Jean Arago began to advocate the use of "photogrammetry", using the daguerreotype, in front of the French Arts and Science Academy.

DEVELOPMENT CYCLES

The developments in photogrammetry, from around 1850, has followed four development cycles [Konecny, 1985]. Each of these periods extended about fifty years. These cycles include:


Figure 1. J. N. Niepce.


Figure 2. Jacques Daguerre.

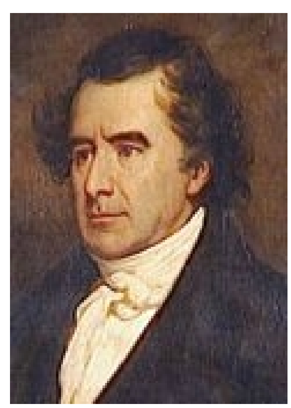
Figure 3. Dominique Arago.

a) Plane table photogrammetry, from about 1850 to 1900,
b) Analog photogrammetry, from about 1900 to 1960,
c) Analytical photogrammetry, from about 1960 to present, and
d) Digital photogrammetry, which is just beginning to be a presence in the photogrammetric industry.

Konency's [1985] development cycles are based upon the economic theory of Kondratjew. Before each cycle, a basic invention is present. The first practical instrumentation follows in 10-15 years. Anywhere from 20-25 years after the invention the new technology begins to be used in normal practice. This technology is then utilized for 25 years after which it shares the market with the new developments from the next cycle for an additional 25 years or so.

PLANE TABLE PHOTOGRAMMETRY

In 1849, Aimé Laussedat (April 19, 1819 - March 18, 1907) was the first person to use terrestrial photographs for topographic map compilation. He is referred to as the "Father of Photogrammetry". The process Laussedat used was called iconometry [icon (Greek) meaning image, -metry (Greek) which is the art, process, or science of measuring]. In 1858, he experimented with aerial photography supported by a string of kites. In 1862, Laussedat's use of photography for mapping was officially accepted by the Science Academy in Madrid. He also tried balloon photography but abandoned it because of the difficulty of obtaining a sufficient number of photographs to cover all of the area from one air station. At the Paris Exposition in 1867, Laussedat exhibited the first known phototheodolite and his plan of Paris derived from his photographic surveys. These maps compared very favorably to earlier maps compiled from conventional field surveys.

Figure 4. Aimé Laussedat medal.

Plane table photogrammetry is an extension of the conventional plane table surveying [Konecny, 1985]. Each exposure station was determined by resection and plotted on the plane table. The exposed photos were oriented on the plane table and the directions to the different objects were transferred onto the map sheets.

With the advent of photography and the ability to make exposures from the air, it was soon found that there were military applications to this technology. In 1855, Nadir (Gaspard Felix Tournachon) used a balloon at 80-meters to obtain the first aerial photograph. In 1859 the Emperor Napoleon ordered Nadir to obtain reconnaissance photography in preparation of the Battle of Solferino. During the American Civil War, balloon photography was obtained during the Battle of Fair Oaks and the City of

Richmond. To transfer points from the photography to the map, a grid overlay was used. In the Franco-Prussian War during the 1870s, the Prussian army installed a photo field detachment to obtain stereophotos, most notably of the fortification of Strasbourg [Gruner, 1977].

Figure 5. Ignazio Porro

Paulo Ignazio Pietro Porro (November 25, 1801 – October 8, 1875) was an Italian geodesist and optical engineer. As a geodesist, he invented the first tacheometer (his instrument was called a tachymeter) in 1839. In 1847 he was able to improve image quality of a lens system all the way to the edges by using three asymmetrical lens elements. He also developed an erecting lens imaging system in 1854. In 1865 he designed the photogoniometer. This development is significant in photogrammetry because of its application in removing lens distortion. His approach was to look at the image with a telescope through the camera lens. This concept was also independently considered by Carl Koppe (1884-1910). Therefore, this concept is called the Porro-Koppe Principle. In 1868, the Frenchman Chevallier developed a "photographic plane table". This camera exposed the photo plate in a horizontal position. The light rays were deflected at right angles by using a prism attached to the sighting device that could be rotated.

In 1885, George Eastman used nitrocellulose as a film base and later (1890) replaced the photographic dry plate for roll film [Gruner, 1977]. F. Stolze discovered the principle of the floating mark, which is used for stereoscopic measurements. C.B. Adams in the U.S. invented radial line triangulation in an effort to graphically solve the principles in plane table photogrammetry to balloon imagery.

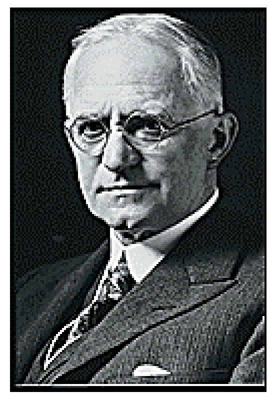

Figure 6. George Eastman.

In 1893, Dr. Albrecht Meydenbaur (April 30, 1834 - November 15, 1921) was the first person to use the term "photogrammetry". He founded the Royal Prussian Photogrammetric Institute and served as its director until 1909.

Meydenbauer is known for his architectural surveys using photogrammetry. Believing that current cameras were not suitable for photogrammetry, he designed his first camera in 1867. This was the first wide-angle lens used for mapping – 105^{o} Pantoshop lens. It was used for the topographic map of Freyburg, Germany, and the structural drawing of St. Mary’s Church. The camera has the following characteristics that are found in metric cameras [Meyer, 1987, p.184]:

Figure 7. Albrecht Meydenbaur [from Meyer, 1987].

- "sturdy body,
- permanently mounted lens,
- spirit levels for leveling up the camera,
- device for aligning the camera axis, and
- definition of the image plane by a frame with fiducial marks for the coordinate axes."

Meydenbaur's method of map compilation utilized the approach at that time. The photograph was used to map the terrain by intersection. Directions from ground control points were graphically plotted from the imagery. Conventional surveying was used to locate the position of the cameras and a few control points in the scene being photographed. According to Meyer [1987], a good draftsperson could obtain the photographic coordinates using dividers to an accuracy of about 0.1 mm. The resulting map would have an accuracy of about 0.2 mm. High accuracy was achieved in Meydenbaur's methods because he used a large format size (40 cm x 40 cm) and his selection of the ratio between the photo scale and map scale, which seldom exceeded a factor of 2. In addition, he utilized mirror glass for the emulsion substrate to maintain the required film flatness during the exposure.

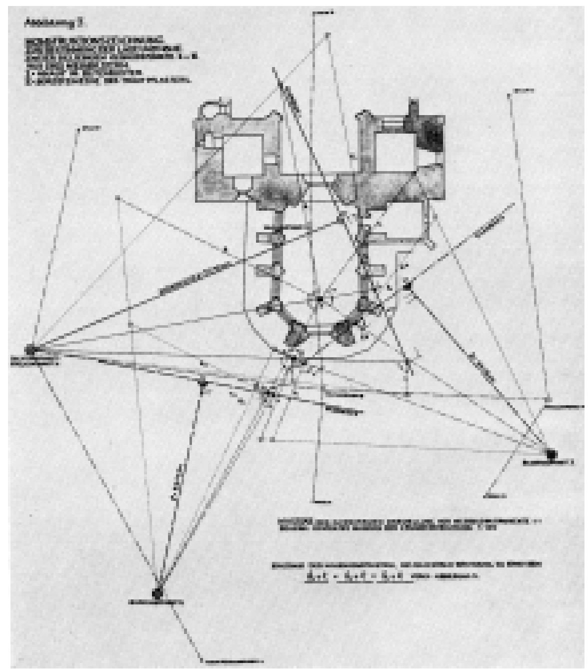

Figure 8. Meydenbaur's principles of photogrammetry [from Meyer, 1987].

Meydenbaur continued to work on different camera designs. For example, in 1872 he developed two new cameras using a smaller 20 cm x 20 cm format. One had a focal length of 12 cm and the other 21 cm. The significance of this camera was that the plates were changed after each exposure. This was done using a light-tight container. To change the film, the camera was removed from the tripod and placed in the container [Meyer, 1987].

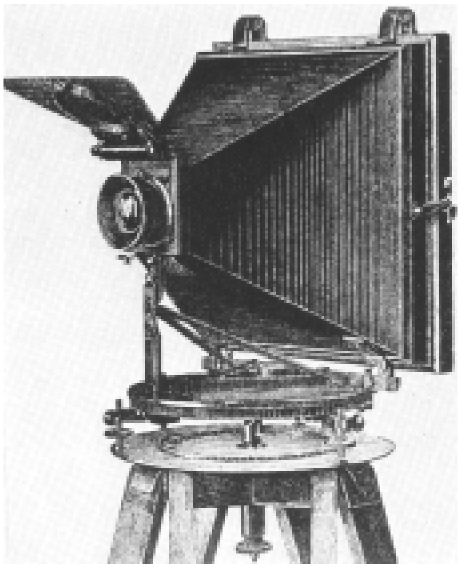

Figure 9. Meydenbaur's camera developed in 1872 [from Meyer, 1987].

ANALOG PHOTOGRAMMETRY

Two important developments were required to advance photogrammetry to its second phase - analog photogrammetry [Konecny, 1985]. First, stereoscopy was becoming widely used. Second, the development of the airplane by the Wright brothers in 1903. This provided a better camera platform than the terrestrial camera.

In Canada, Edouard Deville (February 26, 1849 - September 21, 1924), the Surveyor General of the Dominion, invented the first stereoscopic-plotting instrument called the Stereo-Planigraph in 1896. While this was the first attempt to use stereo overlapping photos, the complexity of the instrument resulted in little use. Stereoscopy was achieved through a Wheatstone Stereoscope to create the stereomodel. Within the model, Deville used a tracer point to perform the mapping [Gruner, 1977]. He was very successful in the mapping of the Canadian Rocky Mountains and is referred to as "Canada's Father of Photogrammetry". Deville used a camera and theodolite mounted on the same tripod (non-stereoscopic photography). In order to transfer the imagery to the map, projective grids (called the Canadian Grid Method) were employed.

Figure 10. Edouard Deville.

Theodore Scheimpflug, an Austrian, developed the theory of the double projector, which offered direct viewing of the projected images. He also presented a method of maintaining a sustained focus in rectification of photographs that is called the Scheimpflug Condition. In order to have sharp focus when the negative and easel (positive) planes are not parallel, the negative plane, easel plane and lens plane (plane perpendicular to the optical axis) must intersect along one line. Beginning in 1899, the German Sebastian Finsterwalder began to publish papers on analytical photogrammetry. When studying the resection of single and double points in space, he showed the existence of a critical surface for single-point resection. Using vector terminology, Finsterwalder showed the analytical conditions that must be met for rays to intersect. In his paper "Die geometrischen

Grundlagen der Photogrammetrie" (Fundamental Geometry of Photogrammetry), published in 1899, Finsterwalder described the principles of modern double-image photogrammetry and the methodology of relative and absolute orientation. In addition, he introduced the necessity of redundant rays to recreate the proper geometry and used least squares theory to describe the relationship of the vectors between corresponding rays.

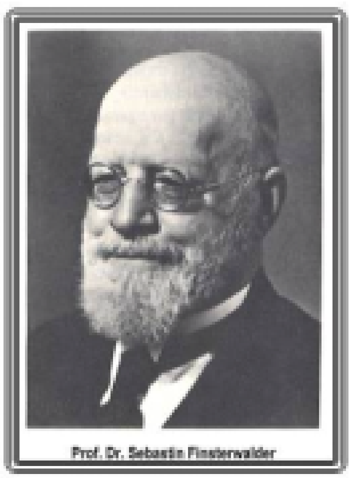

Figure 11. Sebastian Finsterwalder

In 1901, Dr. Carl Pulfrich (September 24, 1858 - August 12, 1929) designed the first stereocomparator employing x and y coordinate scales. This was the first photogrammetric instrument manufactured by Zeiss. Pulfrich is sometimes referred to as the "Father of Stereophotogrammetry". At about the same time, Dr. Henry George Fourcade (July 8, 1865 - January 19, 1948), from South Africa, independently developed a similar stereocomparator. The main difference is that Fourcade utilized grid plates instead of x and y coordinates. He was also the first to discuss the need for reseau in a surveying camera for use with the measuring stereoscope. Because of the independent development, many refer to the stereocomparator as the Pulfrich-Fourcade stereocomparator.

Figure 12. Dr. Carl Pulfrich.

Figure 13. Dr. Henry George Fourcade.

In Germany, Ritter von Orel (November 5, 1877 - October 24, 1941), in 1907, developed the first stereoautograph. this plotter was significant because it's construction principles made terrestrial photogrammetry practical in mountainous areas. It allowed the operator to trace elevation contours directly. The first prototype, using the Pulfrich stereocomparator, was build by the Zeiss Works and employed the geometrical linkage referred to as the "Zeiss parallelogram. The

"Orel-Zeiss Stereoautograph", developed by Pfeiffer and Bauersfeld provided continuous operation without the need for computations required of other plotters. W. Bauersfeld, the chief engineer at Zeiss Works, produced the first stereoplanigraph, which is a universal direct projection stereo instrument. Numerous other individuals made significant contributions to photogrammetric theory and instrumentation. These include Max Gasser who built a double projection plotter for vertical photography (this is the forerunner of the Multiplex plotter) and the Italian Umberto Nistri (1895 - 1962) who created a double projection plotter using alternating image projection.

Figure 14. Professor Reinhard Hugershoff.

Professor Reinhard Hugershoff (October 1882 - February 1941) was a surveyor and photogrammetrist who contributed much to the development of surveying and mapping instrumentation. He created the first analog plotter in 1921 called the Hugershoff Autocartograph. It was a very complex mechanical plotter that incorporated two photogoniometers. The instrument could be used to map both planimetric features and contours. It was universal in that it could be used for terrestrial, vertical aerial, oblique, and convergent photography. He also developed an aerial camera utilizing glass plates that was used to obtain oblique photography by hand or by attaching the camera on the side of the aircraft. When cameras began to be employed through a hole in the fuselage, Hugershoff developed a ring mount that could be corrected for drift (Gruner, 1971).

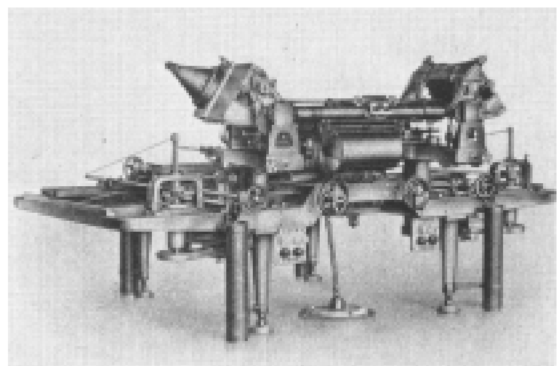

Figure 15. Hugershoff Autocarograph.

Hugershoff also developed a projection plotter where the imagery was projected from below on a light table. Stereoscopy was achieved with a mirror stereoscope. Many of Hugershoff's instruments were used in major engineering projects. For example, he developed a universal phototheodolite that was used in the mapping of the Hoover dam site. This instrument was rugged while still maintaining the highest possible accuracy. It consisted of an eyepiece that was attached to the focal plane thereby making the camera a transit telescope. In an attempt to solve the problems of size in his autocartograph, Hugershoff developed the Aerocartograph in 1926. This instrument used space rods instead of the complex mechanical system used in his earlier instrument. It also had the capability of changing the optical path allowing the operator to view the left photograph with the right eye and right photography with the left eye. This gave the photogrammetrist the ability to perform analog aerotriangulation (Gruner, 1971).

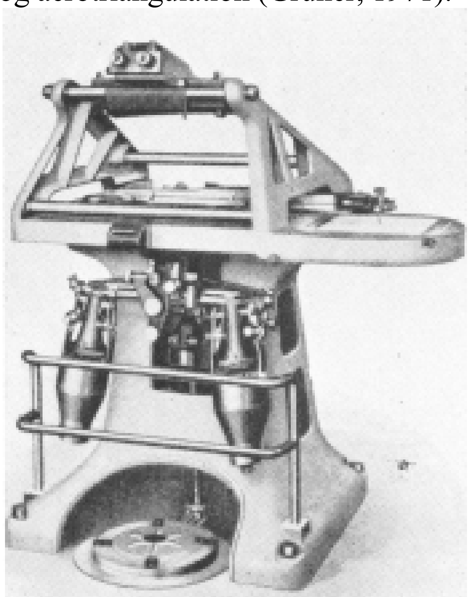

Figure 16. Hugershoff's projection-type Aerosimplex plotter.

One of the unique instruments developed by Prof. Hugershoff was the stereocomparator. It utilized a single light source and single measuring mark. The photographs were moved in X and Y tracks for the measurement process. This design was the predecessor to the Zeiss PSK stereocomparator. These are just a few of the developments attributed to Reinhard Hugershoff. Later in life we worked with Zeiss Works in developing other photogrammetric equipment (Gruner, 1971).

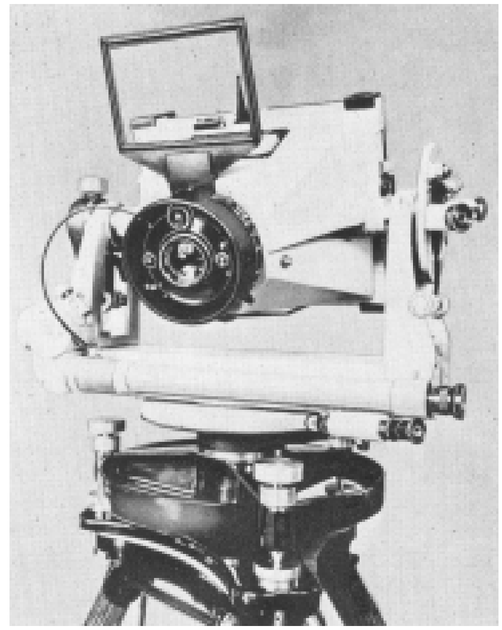

Figure 17. Phototheodolite developed by Hugershoff.

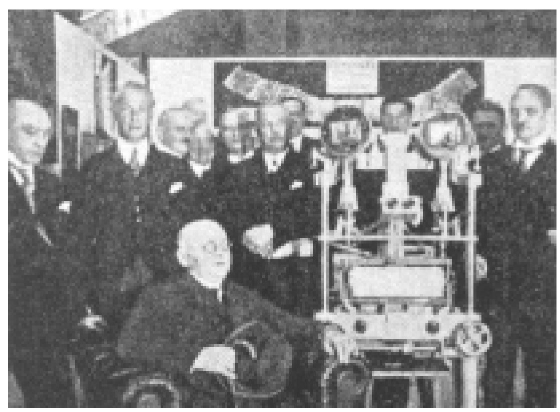

Figure 18. Aerocartograph taken in 1926 in Berlin during the Second International Congress of Photogrammetry.

Otto von Gruber (August 9, 1884 - May 3, 1942) derived, in 1924, the projective equations and their differentials, which are fundamental to analytical photogrammetry. His method of relative orientation of a stereoplotter make the process of orientation easier and quicker. This procedure is still in use today. In a similar vein, Earl Church

(August 11, 1890 - May 11, 1956) also contributed to the theory of analytical photogrammetry. He developed the analytical solutions to space resection, orientation, intersection, rectification, and control extension using direction cosines. Church, a professor at Syracuse University and one of the founding members of the American Society of Photogrammetry, is referred to as the "American Father of Photogrammetry" [Quinn, 1975]. Dr. Bertril Hallert from Sweden is best known for his investigation into errors, stereoplotter orientation procedures, and standards for plotter calibration [Gruner, 1977]

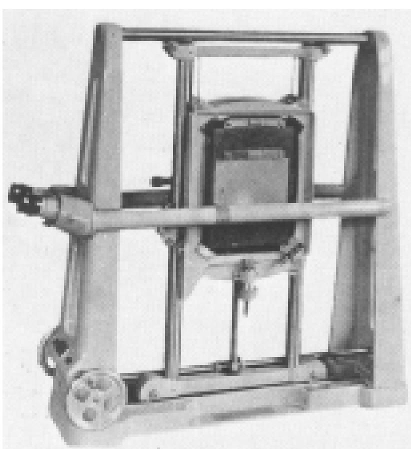

Figure 19. Stereocomparator developed by Hugershoff.

During the early part of the twentieth century, many of the figures in analog stereoplotter manufacturing began to develop their unique brand of instrument. Heinrich Wild, who had already made significant advances in surveying instrumentation, developed the "Autograph". This instrument, which was used for terrestrial mapping, was modified in 1926 to accommodate aerial photography [Gruner, 1977].

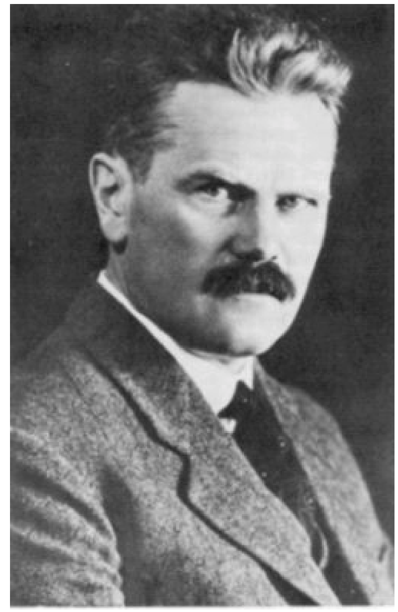

Figure 20. Otto von Gruber.

Figure 21. Professor Earl Church.

In Italy, Professor Santoni, who was at the Officine Galileo, developed the Autoreductor in 1920. This was followed by the Stereocartograph in 1925. In the ensuring years, numerous stereoplotters were introduced into the photogrammetric industry [Gruner, 1977].

Stereoplotters were also being developed by the French. G.J. Poivilliers designed the Stereotopograph in 1919. This began a series of stereoplotters that were used by the French Central Mapping Agency. In 1933, R. Feber developed a direct projection plotter that used alternating image projection [Gruner, 1977].

Early American photogrammetric pioneers included the brothers Arthur Brock Jr. (January 12, 1887-February 10, 1943) and Norman H. Brock (April 23, 1890-January 29, 1965) who, along with Edward H. Cahill, developed aerial cameras and plotting instruments [Tubis, 1976]. They were the first to create an aerial camera that was mounted in the plane instead of holding the camera over the side. Design began in October 1914 with the camera being built at the Sloan and Chase Machine Shop in Newark, NJ.

This camera was very unique and was geared to meet the military needs in war. The camera used the ferrotype in order to provide filed commanders with imagery as soon as possible. An electric motor was employed to drive the camera and a gyroscope was incorporated to keep the lens axis in a vertical direction. The motor moved the ferrotype from the magazine to the focal plane. Once the exposure was made the ferrotype was placed in a magazine that contained developer. The idea behind this design was that upon landing the pilot would take the exposed ferrotypes and place them into fresh water to stop the developing. The camera utilized a 12” focal length with a f-stop of 4.5 with a 4” x 5” image format. The final product did not include the gyroscope since it did not accurately hold the camera in a vertical direction. Moreover, the ferrotypes were replaced with cut film [Tubis, 1976].

The idea of providing an aerial camera that could give the field commanders a large amount of imagery was still important to the Brocks. In 1916 they developed another camera utilizing roll film. It could take 100 pictures per roll (4 ½” wide x about 560” long). To hold the lens in a vertical direction, it was pendulously held in a gimbal and dampened to minimize oscillations. The camera was linked to the instrument panel for the pilot to operate. They could take anywhere between 3 and 10 photographs per minute. One of the significant events associated with this camera is that it was the first war pictures taken by the U.S. Army (war with Mexico).

The Brock mapping process required a number of steps. Tubis [1976, p.1025] identifies the steps as: "(a) producing aerial photographic negatives on glass plates, (b) plotting the horizontal position of the photographs, (c) horizontalizing, or tilt, correcting the photographs, (d) contours and culture delineation, (e) scale equalizing, and (f) assembling the photographic information into final map form". This battery of operations necessitated a series of instruments including an enlarging projector, correcting projector, stereometer and tracing instrument.

The imagery was captured with an aerial camera that had an interchangeable magazine that held 48 glass plates with a 6.5” x 8.5” format. The film was developed and then enlarged onto glass plates. This was done through the Enlarging Projector. The next step is to create templates of transparent paper by placing the overlapping pair of plates on a large stereoscope. These templates are created by a marking tool that perforates both the emulsion of the glass plates and the paper templates. These are done at the conjugate centers, control points, and the end of baselines determined from ground surveys. The templates are removed and used in creating a radial-line plot [Tubis, 1976].

The next step in the Brock process was to correct the imagery by creating new horizontal imagery. Cahill pointed out the difference in the Brock process and the approaches used in Europe. "The fundamental difference between the European and the Brock methods of solution is that knowledge of only the elevations of ground points is necessary in the Brock method, whereas data for both vertical and horizontal positions of points are required by the European methods. In the Brock process use is made of the relation that in a stereoscopic pair of vertical photographs, the coordinates of corresponding images will be in agreement" [Tubis, 1976, p.1025]. The correction was performed using charts and tables in where the tilts were determined in order to rectify the imagery. The set-up used the photographic imagery that had been enlarged and grid screens. Once the corrections were determined, sensitized plates were inserted in the Correcting Projector and horizontal plates were created [Tubis, 1976].

The next step was to perform the mapping by placing the horizontal imagery into the large stereoscope. The map sheet consisted of a stabilized paper superimposed onto one of the photographs. Measurements were performed using two reticules, which acted similarly to the floating marks used today. Once all of the planimetric detail and contours were plotted on the paper, the map was then placed in the Tracing Instrument. This step was required in order to take the map, which was a conic projection, and transform it into an orthographic projection [Tubis, 1976].

One of the more unique aerial cameras developed was the 9-lens camera that Captain O.S. Reading developed for the U.S. Coast and Geodetic Survey. The advantage of this camera is the wide ground coverage. It had a field angle of 140^{o} [Gruner, 1977].

Sherman Mills Fairchild (April 7, 1896 - March 28, 1971) was an entrepreneur who became a very successful businessman in photogrammetry [Doyle, 1980]. He developed a between-the-lens shutter using a rotary blade. This improved the quality of the image because of the sharper definition without the resulting distortion. After forming Fairchild Aerial Camera Corporation in 1920 he developed the K-3 camera and its successors. In an attempt to assist in the sales of aerial camera, Fairchild formed another company that used aerial photography for photomaps. The pilots complained about the planes that they had to use in the photo missions so, using the input from both the pilots and the photographers, Fairchild founded Fairchild Aviation Company and designed a cabin monoplane called the FC-1. While Fairchild was continually building upon his previous camera designs, two notable cameras are worth merit. The first is the 9-lens camera developed for the US Coast and Geodetic Survey that consisted of 1 vertical and 8 oblique photographs. The uniqueness of this camera is that all of the lenses were mounted vertically. The images were formed by reflection of front-surface mirrors. Fairchild's company also developed the Lunar Mapping Camera that was used on the Apollo 15, 16 and 17 missions.

In 1936, Robert Ferver, from France, was awarded a U.S. patent for the Gallus-Ferber Photorestituteur which was the first orthophoto production instrument although it was not used much because it was not economical [Lawrence et al, 1968]. This plotter consisted of an anaglyphic projection that was used to raise or lower one of the projectors. The movable projector did not have a filter attached to it. In the U.S., Russel Kerr Bean made significant contributions in photogrammetric instrumentation. In 1956 he was awarded a patent for an "Ellipsoidal Reflector Projector for Stereo-Photogrammetric Map Plotting" known as the ER-55 and it was used by the US Geological Survey (USGS) during the 1950s and 1960s [Radlinski, 1985]. This plotter accepted stereoscopic imagery not only from vertical photography but also convergent low oblique and transverse oblique photography. This plotter was later manufactured by Bausch and Lomb Optical Co. as the Balplex plotter. In 1959 he was awarded a patent for an orthoscope. This instrument produced photography at the same level of accuracy as a map at a fraction of the cost. Bean's orthophotoscope was different from Farber's instruments in that it employed a movable film surface. The surface had a slot on it which allowed for movement - the X and Y directions [Lawrence et al, 1968]. Bean also developed a camera calibration system consisting of a bank of collimators which also projected resolution targets onto the film.

Harry T. Kelsh (November 15, 1889 - January 30, 1979) made an important contribution to photogrammetric instrumentation in the development of the Kelsh stereoplotter in 1945. This optical projection plotter offered private photogrammetrists the opportunity to perform accurate mapping without the expense that was required for the European stereoplotters.

Instrument makers have had significant influences on photogrammetric developments. In 1819, Kern of Aarau, Switzerland, was founded and began manufacturing precision surveying and mapping instruments. Kern introduced the highly popular PG2 analog stereoplotter. Over 700 of these instruments were sold worldwide. In 1980, Kern introduced the DSR1 analytical stereoplotter.

Wild Heerbrugg was founded in 1921. They became a world leader in the manufacture of accurate surveying and mapping instruments. Their A8 and B8 Aviograph stereoplotters were very successful analog instruments with over 2,000 sold worldwide.

In 1988, Kern and Wild merged and eventually formed Leica in 1990. Using the expertise from both companies, the SD 2000 analytical plotter was launched in 1991. In 2001, Leica acquired Azimuth Corporation, ERDAS, and LH Systems giving Leica the capabilities of offering clients LIDAR scanning systems, remote sensing/image processing software packages, and digital stereoplotter capabilities.

ANALYTICAL PHOTOGRAMMETRY

The invention of the computer (by Zure in Germany in 1941 and independently by Aitken in the US in 1943) made significant advances to photogrammetric developments after 1950 [Konecny, 1985]. It is responsible for the third cycle of photogrammetric development - analytical photogrammetry. In 1953, Dr. Hellmut Schmid, at the Ballistic Research Laboratory, Aberdeen, Maryland, developed the principles of modern multi-station analytical photogrammetry using matrix notation. The important features of his approach included a rigorously correct least squares solution, simultaneous solution of any number of photographs, and a complete study of error propagation. Duane Brown is also responsible for continued work in analytical photogrammetry while working with Schmid and later in private industry.

The father of the analytical plotter is Uuno (Uki) Vilho Helava (March 1, 1923 – June 6, 1994). Born in Finland, Helava moved to Canada as a research fellow at the National Research Council (NRC). While at NRC, Helava developed the analytical plotter in 1957. This instrument used servocontrol instead of the optical or mechanical construction of previous instruments [Konecny, 1985]. A computer was used not only to drive the instrument around the stereomodel but also to digitally transform coordinates between the image and the map.

DIGITAL PHOTOGRAMMETRY

In 1958, Gilbert Hobrough, from Canada, developed the image correlator. This instrument is an important part of the digital photogrammetric cycle where it is used for digital terrain model production and the development of rapid electronic orthophotographs.

Uki Helava also played a central role in the development of digital photogrammetry, first as a research scientist at Bendix and later at Helava Associates, Inc. (1979). Helava Associates eventually became a subsidiary of General Dynamics in 1986 where he helped develop digital photogrammetric workstations for the Defense Mapping Agency (now called NIMA). When General Dynamics divested its Electronics Division in 1992, Helava Associates became GDE Systems. It formed a joint partnership with Leica Geosystems in 1997 forming LH Systems. Now, LH Systems is a wholly owned subsidiary of Leica Geosystems.

PROFESSIONAL ORGANIZATIONS

While still a fledging profession, scientists and professionals began to gather to exchange ideas and developments within the industry. In 1907, Edward Doleźal helped form the Australian Society for Photogrammetry, the first photogrammetric organization [Albota, 1976]. Two years later, the International Society for Photogrammetry was established and Doleźal was installed as its first president [Gruner, 1977]. The American Society for Photogrammetry was formed in 1934.

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