SURVEYING - 1776 TO 1976

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BIOGRAPHICAL SKETCH

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ABSTRACT

In 1776, surveying was considered as the "art of making measurements to determine the relative positions of points on the surface of the Earth." Maps were drawn, based on these measurements. Boundaries were defined; areas were calculated and described. In 1976, the same tasks exist. The industrial and technological advances of the intervening two centuries have brought new methods, have modified "art" to "science and engineering," and have expanded the "horizon" to cover the entire Earth with intercontinental relationships and even include the moon and other planets. In this brief review, some of the step-by-step developments in various surveying operations are identified. These techniques include measurement of lengths, measurement of directions or angles, construction of observing platforms, design of targets and signals, determination of position, and the calculations with the computers and mathematical analysis to support all the work.

INTRODUCTION

Two hundred years ago, surveying was defined as the "art of measuring the relative positions of points on the land." Today, geodesy is defined as a "science" and other branches of surveying are classified as part of engineering or related technology. This change in terminology does not necessarily indicate a basic change in the philosophy of surveying. The problems or tasks do not change but the manner in which we solve those problems or tackle the tasks has become more sophisticated. We have benefited from the evolution of technology. Some may say that we have replaced the "art" with a little "black box."

When I was asked to prepare this review of surveying in the United States during the past two hundred years, I soon sensed that volumes could be written--in fact, they have been. What approach should I use? Should I describe survey operations, trace the growth and expansion of our country, identify those men who made outstanding contributions to surveying? During this bicentennial year there have been several papers written which describe these historical aspects, so I decided to review some of the technological contributions to our profession. By reflecting on the innovations made by our predecessors, we gain a greater appreciation for the comparitive ease of our tasks today.

COMPASSES AND CHAINS

In colonial days, surveying was primarily a matter of "running lines" between points either to establish a boundary or, with a series of lines, to bound a piece of land. The number of instrument makers who could make a surveyor's compass was large--historians indicate probably more than three hundred. Most of the compasses had needles 5 to 6 inches in length and many were supported in wooden cases with folding wooden sights. Recently I read, "The scarcity of brass led the colonial instrument makers to seek substitutes and by the early eighteenth century they had resorted to hardwoods. The instruments required for the surveyor were duplicated in wood from metal examples with considerable skill, and wooden surveying instruments came into common use." I am inclined to differ with this modern interpretation. Rather than a "scarcity of brass," I believe that the surveyors of that period knew that any impurities in a brass support for a compass needle would produce systematic errors. They could determine the declination of the compass by making celestial measurements. Those who were interested in the quality of their work much preferred the compass in the wooden case. Some of the innovations to the compass included the use of verniers and also the addition of a large, 12- to 14-inch diameter, graduated circle with a set of sights revolving around the same center as the magnetic needle. This permitted measuring the angle between two objects as well as reading the magnetic bearing to each. This modified compass was known as a circumferentor.

The colonial surveyors used Gunter chains for measuring most distances. The number of paces to reference points appear in some descriptions. For greater accuracy they used brass-tipped pine or fir poles which had been soaked in boiling linseed oil to prevent absorption of moisture, a major contributor to change of length. However, the chain was a basic item in the surveyor's list of equipment. The relation of its length to the English unit of area, the acre, greatly facilitated the computational work for the colonial surveyor, and still does today for the public land surveyor. It was well known that continued use of the chain would result in a change of its length, but the types of terrain and the ground cover were factors contributing larger errors. An old Virginia law of 1779 acknowledged that there might be five acres excess in each 100 acres. When the contracts were being awarded for Public Lands Surveys, the set of instructions issued by the Surveyor-General at St. Louis in 1843 would permit accumulated errors of five chains in a township or one chain per section. One and a half chains per mile were permissive for meandering lines. In later years, the limits were stricter. Instructions of 1930 used a ratio: one part in 452.

Tapes gradually replaced chains, and during this past quarter century, EDM, electronic distance measuring equipment, has become part of the surveyor's inventory. A misclosure of one link per section is reasonable, an improvement of two orders of magnitude in accuracy. But tapes have not been discarded. Manufacturers continue to list, in their catalogs, tapes of 66- and 132-foot length with subdivisions in links. In 1976, all manufacturers are listing tapes subdivided in metric units. These are essential as we begin to calculate areas in hectares rather than acres.

THEODOLITES AND TRANSITS

When we trace the development of theodolites and transits, there are several interesting points which merit identification. Ramsden of England had built a theodolite with a 36-inch horizontal circle. The direction of the telescope was read with three equally spaced microscopes, forerunners of modern micrometers. The French had developed a repeating theodolite, mounted so that the graduated circle could be rotated to the plane of the three points of the triangle; the angle at the observing point measured by repetition. The English philosophy of referencing the measuring circle to the local gravity vector rather than the plane of the three points has prevailed. Later the French adopted the concept of measuring the angle in the horizontal plane, but they continued to favor the practice of repetition. Ramsden, in addition to making theodolites, built graduating engines. He cut 2160 evenly spaced teeth around the circumference of a 36-inch plate. One full turn of a worm driving screw was equal to one tooth or 10 minutes of arc. A micrometer drum head on the shaft of the driving screw permitted dividing the 10-minute interval into smaller parts.

Hassler imported several theodolites for his initial work on the "survey of the coast," the largest had a 36-inch horizontal circle. You have read the accounts of the special carriage he had constructed to transport it. When theodolites were first made in the United States, the size had decreased to 24-inch, later to 12-inch, and then to 9-inch, the Parkhurst theodolite. For many years this was the basic first-order instrument of the Coast and Geodetic Survey and was used during the 1930's, the time of the Great Depression, when the work of the Survey was expanded through the use of public work funds. During the same years, the T2 and T3 models of Wild theodolites were being introduced into the United States. Because of the smaller size and lighter weight of these new optical reading theodolites, the Parkhurst and all the other larger types were soon items for the warehouse or museum.

In the early days, the land surveyor did not consider the theodolite very suitable for his work. The bulkiness, weight, and extreme care required for their use were discouraging factors. He preferred the compass and strived to make improvements to it. William A. Burt, who was a surveyor, inventor, and instrument maker, obtained a patent in 1824 for a solar compass. He had attached a small telescope to a compass so that by observing the Sun or Polaris, the magnetic declination could be determined. We find a reference that "William J. Young invented the transit instrument in 1831." This was among the first of the engineer's transits. The earliest models were about the size of the surveyor's compass, but in contrast to the trend of theodolites, the engineer's transits became larger with more attachments and larger circles. The limit of reading an angle on the smaller instruments had been about three minutes. By increasing the size of the circle, improving the quality of graduation, and perfecting the verniers, the instrument maker soon obtained at least 30 seconds; and when angles were repeated, values correct to a few seconds could be obtained. In more recent time, the instrument maker has been able to reduce the size of transits and improve the quality. The surveyor of today has a wide range of types and styles from which to make a selection for his particular field of surveying.

TARGETS AND SIGNALS

With the improvement of surveying instruments used for measuring angles, there has been an associated evolution of targets or signals to be sighted. The early surveyor, with a compass having slit sights, used a rod. Rods have not been modified to any great extent except for the types of paint. When telescopes were used for longer lines of sight, some ingenuity had to be used.

For some of the first triangulation, spheres, 16 to 20 inches in diameter were made from barrel hoops covered with white lines and elevated on poles. These could be seen as far as 10 miles with the naked eye in clear atmosphere. However, some difficulty was encountered along the sea coast because of haze. Hassler designed a truncated cone made of sheet tin. The angle of the cone had to be favorable for morning and evening illumination. It was necessary to correct for the angle of the sun at the time observations were made. This basic concept was used some 50 years later for a permanent signal on Mt. Shasta. In late September of 1875, a party ascended Mt. Shasta with prefitted materials to place a signal on the 14,400 foot summit. A three-foot reflecting conoid, which was copper and nickel plated, was mounted above a cylindrical shaft made of galvanized iron plates. This shaft was 2 1/2 feet in diameter and 14 feet high. In retrospect, this seemed to be more of a test of man against the elements than an experiment on the feasibility of using reflecting targets.

Heliotropes were used for many years. The men who tended these, the 19th century "light keepers," developed considerable skill. The slow motion screws for rotating the mirror had to be "touched" three or four times per minute. The length of line and clearness of the atmosphere were factors to be considered in selecting the size of the mirror. The theorists even proposed a formula. For ordinary conditions, the formula, $x=0.046d$, was used, x being the side of a square mirror in inches and d the distance in miles. For example, a three-inch mirror for 65 miles or 4.6 inch for 100 miles.

In 1878 an observing party ascended Mt. Shasta, three years after the special target had been placed, and made observations to Mt. Helena, 192 miles distant, and Mt. Lola, 169 miles. The Mt. Shasta-Mt. Helena line is the longest in the United States network. A heliotrope with a 12-inch square mirror was used on that line. One of the reports on some of the work contains the following statement: "On long easterly and westerly oriented lines, the curious phenomenon of getting reflected sunlight thrown to the station at which the sun was already below the horizon was frequently observed, and at times lasted several minutes."

The records show that some observations were made using the light of the Moon. The device was appropriately referred to as a selenotrope. The size of the mirror had to be increased. For example, for lines approximately 50, 70, and 100 miles in length, the mirror sizes were 6 x 8, 8 x 10, and 12 x 18 inches.

In the 1870's, experiments were initiated on the use of signal lamps. In 1874, kerosene oil was used as a source of illumination using special reflectors and lenses to project the light. In 1875, a significant improvement was made using magnesium tape in focus with an 8-inch reflector. The costs of that day were considered high. The lamp cost $36 and burned 15 inches of magnesium tape per minute at a cost of $1.40 per hour. However, we should note that the power of the light was great. At 40 miles, as seen with the naked eye, the light was nearly as large as Jupiter.

The next modification was to adopt the acetylene bicycle lamp. A few years later, the old type automobile headlight reflector, with a special filament bulb, became the standard. The lamps were placed in wooden frames with the focal points centered over holes which permitted stacking two or more on a light stand. With large multiple observing parties, as many as six lights might be centered over a station, each showing in a different direction.

The next change was that the frames were made of sheet metal and then later cast aluminum as a means of decreasing the weight and making them more resistent to the weather. These lights have been observed on lines as long as 150 miles. A 6 volt, 1.5 ampere bulb light casts a beam of over 70,000 candlepower at 100 feet.

One of the latest developments is an omnidirectional showlight. It consists of a high intensity bulb, revolving nine times per minute. There are eight focusing lenses in the showlight giving it 72 flashes a minute. A telescoping tower is used to elevate the light. When night observations are made in an urban area, the distinguishing flashing pattern of this showlight is very helpful for the identification of the signal among the hundreds of lights on the horizon in the general vicinity of the target.

SURVEY TOWERS

For most boundary or land surveys, the general practice has been to clear the lines of sight. For triangulation, if the lines could be cleared with a minimum of cutting, this also was done. However, in most instances, the extent of clearing was prohibitive and observing towers had to be constructed. Sometimes it was more convenient to use poles cut from nearby timber but the usual procedure was to construct the double tower from lumber, inner for instrument support and outer for observer support. Frequently, these towers were 100 feet in height. Occasionally signals or targets were extended another 100 feet above the observer's platform. The total structure would require many guys. One such tower was erected in 1896 at Still Pond, a station on the eastern shore of Maryland. The inner instrument stand was 120 feet in height and the target on top of an extended pole was 275 feet high. In 1878 along the California Coast in redwood country, at station GREAT CASPER, a four sided instrument stand was built around a redwood which had been topped to a height of 135 feet. The observer's platform consisted of a super-structure fastened to the topped tree.

The costs of constructing such towers became so great that in some sections of the country, precise traverses were measured to extend the primary control network. Very few towers were needed. The economic factor also encouraged the development of a portable steel tower. By 1927, Jasper Bilby had perfected such a tower. The Bilby tower has been accepted internationally as a standard of excellence. In the last few years, the desire for greater automation has resulted in the development of lighter weight towers which are very effective for heights of 40 to 60 feet but, as yet, nothing has replaced the Bilby towers which can be constructed to 120 feet without guying.

METRIC STANDARDS AND BASE LINES

The evolution which has occurred in the measurement of geodetic base lines is one of the most remarkable in the whole field of surveying. There is not time to give all the details so I will endeavor to summarize. For those who have an interest, you will find well written descriptions of the various methods which have been used.

The unit of length for geodetic base lines in the United States has always been the metre. Up to 1890, the reference standard was an iron metre bar brought to the United States by Hassler in 1805. You will recall that the Coast

Survey was established in 1807 with Hassler its first Superintendent. This iron metre bar had standardized at Paris in 1799 by the Committee on Weights and Measures. The bar was one of sixteen made by Lenoir. Eleven others of the original sixteen were distributed to other countries. Hassler presented the bar to the American Philosophical Society of Philadelphia, which later made it available to the Coast Survey. As the reference standard, this iron bar was identified as the Committee Metre or C.M. At various times, Hassler and several others made thorough investigations of its coefficient of expansion. In 1867, the C.M. was taken to Paris for direct comparison with the standards preserved there. Those who were using this bar as a standard hoped that any uncertainty in its length would be less than one micron. They concluded that an error of one part per million was only four metres in the width of the country and assumed this would be a negligible amount in comparison with errors of triangulation. No one would have imagined using Doppler satellite positioning with uncertainties of the order of a metre or laser ranging or VLBI to perhaps four centimetres--two orders of magnitude better than the one in a million.

In the late 1860's, it was recognized that the various copies of the French standard metre differed among themselves by amounts that were larger than were acceptable to the scientific standards of that time. The French government invited the other countries to send delegates to Paris to form an International Commission, having for its object the construction of a new metre as an international standard of length. The United States accepted this invitation and sent Joseph Henry of the Smithsonian Institution, and J. E. Hilgard of the Coast Survey, as delegates. In 1875, a treaty was signed by representatives of 17 countries establishing a permanent International Bureau of Weights and Measures. For the next several years, work proceeded on the selection and testing of materials. By 1889, the group at Paris was ready to distribute the new standard known as the International prototype. The metre bars, line bars in contrast to the end bar style of the Committee Metre, were made of an alloy, 90% platinum and 10% iridium. Two of these standards were received in 1890 by the Coast and Geodetic Survey and then transferred in 1901 to the National Bureau of Standards when that Bureau was organized.

As the requirements for greater accuracy in metrology increased, the General Conference of Weights and Measures recognized that it was "desirable to adopt a natural and indestructible standard." In 1960, that international body defined the metre as "the length equal to 1 650 763.73 wavelengths in vacuum of the radiation corresponding to the transition between the levels of $2p_{10}$ and $5d_5$ of the krypton-86 atom."

I can only comment that the surveyor still has the problem of transferring that definition or standard to a field measurement either by comparison of his equipment at calibration sites established and maintained for that purpose or by tests at the National Bureau of Standards. The precision of the more refined standard may be completely lost in this transfer operation to field measurements.

There are several detailed reports on the construction and use of precise base measuring equipment used in the 19th century. I have selected a few of the key points to trace the development and show certain similarities to the approaches used today to solve comparable problems. It is essential that these old published reports be preserved and be available for future reference.

Hassler published, in the Transactions of the American Philosophical Society, a very complete description of the apparatus he developed. This equipment, with some later modification, was used to measure three base lines: Fire Island in New York, one in Massachusetts, and Kent Island in Maryland. For his apparatus, Hassler prepared four 2-metre iron bars, similar in design to the C.M. After carefully standardizing these, he bracketed them, end to end, and placed them on a frame which permitted movement of the 8-metre bar for alignment along the base and for placing in "contact" with the preceding position of the bar. The whole system was mounted in a long box, about a foot in width and height and almost 30 feet in length. It had no cover except canvas. The "contacts," optical rather than physical, were accomplished with microscopes positioned on independent tripods. Three such optical systems were used, the rear-rear one always maintained in position until the other two had definately fixed the forward contact. The box containing the apparatus was placed on five special tripods having elevating screws. In the field, a set of these five tripods was placed in position in advance of moving the box.

We should note that Hassler attached four thermometers, one to each 2-metre bar. Quoting from his report, "Respecting the thermometers, it will not be necessary to say anything here, as it is easily conceived that they must be read at each laying of a box." As the knowledge of the behavior of metals increased, it became apparent that the effect of temperature was one of the major sources of error. Different types of temperature-compensated bars were constructed. The lengths varied from 4, 5, to 6 metres, somewhat shorter than the Hassler apparatus. Combinations of iron, steel, brass, and/or zinc were used.

One system consisted of two steel rods in combination with a zinc tube. One end of the first steel rod was fastened to an end of the zinc tube, and the other end of the second steel rod was fastened to the opposite end of the zinc tube in what might be described as a folded position. The zinc, with its coefficient of expansion roughly 2 3/4 times that of steel, would expand in an opposite direction to the steel, producing the compensating effect. The cluster of three rods was placed in a controlled tube and had devices on the extensions of the ends of the steel rods for making the contacts.

Another system developed by William Eimbeck used the principle of measuring the difference in length of two bars, such as steel and brass, to determine the inherent temperatures of the metals. The two bars were attached at one end and the difference in length measured with a microscope from accurately engraved divisions on the other ends. The temperature of the system was thus determined. There is a striking similarity to the use of two colors of lasers in geodimeters to determine the mean temperature of the air along the line of sight.

More insulation to control the temperature was used on some systems. One modification was to place the bar in a trough packed with crushed ice. That system required about 500 pounds of ice per hour. That system, because of the weight, required a car-like device with special wheels and sections of track which had to be lifted and then laid in advance of the measurement. It might seem complicated but field reports indicated that rates of progress of 100 meters per hour were achieved.

In 1881, the Yolo Base in Sacramento Valley was measured with a set of compensated bars. A special mobile protective shelter was constructed. In later years it was called the "Yolo Buggy." It was 50 feet long to provide protection for three 5-metre bar systems in position, 12 feet wide to provide working room to move the systems, and 9 feet high. The total frame, when loaded with necessary equipment, weighed 1500 pounds. The wheels, fore and aft, were large enough to permit movement by four men, one at each corner. The special cases containing the bars weighed 160 pounds each and were moved forward by two men. Tripods to hold the cases weighed 35 pounds each and rested on three iron plates weighing 9 pounds each. When measuring, three systems were in alignment. Rear contact was established for the middle system. Then, the whole unit, shelter and all personnel, could advance the length of one bar or five metres. Thirty bars per hour or a kilometre per day was average progress. I can visualize that the operation required approximately 20 men working as a well-drilled team.

About 1890, some tests were made with steel tapes comparing the results with the special compensated bar apparatus and also the iced bar. These tests were successful and field procedures for base measurement soon changed. The temperature problem still persisted, but most precise measurements were made at night to minimize the problem. Within a relatively short time, an alloy of nickel and steel known as invar was used to manufacture tapes.

In 1906, six base lines were measured with both steel and invar tapes. The average difference in lengths was one in 526,000. This ratio corresponds to an uncertainty of 0.17°C for the steel tapes or, by comparison for invar because of the varying coefficients, uncertainties could be 4 or 5°C. Owen B. French, in analyzing the results of these tests concluded "an error of 0.17°C in determining the temperature of steel tapes, either in the standardization or in the measuring or in both, is not only possible but probable." The characteristics of invar with its low coefficient of thermal expansion permitted a return to daytime operations. The major concern was the lack of stability of the alloy. Extra care in handling and more frequent standardization controlled this problem. The costs of measuring base lines decreased tremendously, and the accuracy increased.

In 1948, Bergstrand, a Swedish physicist-geodesist, demonstrated a new concept for measuring distances. He had been experimenting for a few years with techniques for measuring the velocity of light. By projecting a modulated light beam to go and return, he was able to determine the distance. He called this instrument a geodimeter. The concept has been modified in different ways to produce a whole family of EDM, electronic distance measuring equipment. The most significant improvement to the geodimeter was the use of a laser as the light source. Again, the cost per base line decreased and the accuracy increased significantly. The accuracy feature is dominant and has been the key factor in the recognition of the superiority of trilateration over triangulation when extreme accuracy is a requirement.

It is interesting that Bergstrand first used a plane mirror to reflect the light beam. This required continuous monitoring at the mirror position because of changing refraction. About 1945, some tests had been made by the U.S. Corps of Engineers on tetrahedron prisms as survey signals. It was stated in a published report that the tests were "not too encouraging." But the corner cube array was an ideal solution to Bergstrand's problem and their use has extended far beyond terrestrial surveying. You are familiar with lunar laser ranging.

ASTRONOMICAL POSITIONS

One of the fine arts of surveying has been the skill for determining one's position on the Earth's surface in terms of latitude and longitude. In today's three-dimensional concepts, these two coordinates are frequently combined with the height, but for this review, we must trace each component.

A standard method for determining latitude in colonial times was to use a zenith sector to observe stars close to the zenith as they crossed the meridian. This instrument had a telescope six feet in length and short graduated arcs for measuring the zenith angle. Sensitive spirit levels defined the verticality. The observer had to lie flat on his back while observing. An astronomical latitude accurate to two or three seconds of arc could be obtained from observations on six or eight stars.

The next step was to attach a full vertical circle and a prismatic eyepiece. This increased the number of stars which could be observed but introduced problems relating to refraction. Captain Andrew Talcott of the U.S. Corps of Engineers, while measuring latitudes along the Ohio-Michigan Boundary in the 1830's, suggested further modifications. By using pairs of stars, one north and one south approximately the same distance from the zenith, the uncertainties contributed by refraction could be reduced. The zenith telescope evolved by improving the mounting of the telescope in a fixed zenith distance for reversal, by increasing the sensitivity of the levels, and by using an eyepiece micrometer to measure the difference of zenith distances. It is reasonable to assume that Talcott did not know of Peter Horrebow's announcement of the same concept in his Atrium Astronomiae in 1732. Today we know the method as Horrebow-Talcott.

In later years the astronomical instruments were further modified by placing the prism in an interior position such as in the broken telescope type. By changing the eyepiece, these could be used for either latitude or longitude. Familiar types were the Bamberg and Askania. In more recent years, Wild produced the T4 Universal theodolite which has been used in the same way.

We should note that zenith telescopes are still used as the fundamental instruments in the International Polar Motion Service for monitoring the variation of latitude. Some of these instruments have been in use for almost 80 years providing an observational data base that is one of the finest sources available for studies of the rotation of the Earth.

The determination of longitude introduces the dimension of time. In colonial days, local sidereal time could be determined by measuring the altitudes of east and west stars or by observing the time of transit of stars on the meridian. The problem was to determine the difference of longitude between the local meridian and the meridian of Greenwich or some other observatory. Various solutions were to observe the eclipses of Jupiter's satellites, the culmination of the moon, or the angular relation of the moon to selected stars. Another solution was to transport chronometers. For the last, the quality of the results naturally were dependent upon the quality of the chronometer and the care used in transporting.

With the development of Morse's telegraph, it was possible to transmit signals and syncronize the chronometers at two observing points which were close to telegraph stations. The first test was in 1847. In 1858, George Davidson prepared plans for a meridian transit designed for both latitude and time determinations. The longitude eyepiece had a diaphragm with etched parallel lines for noting the time of transit. Each observer had is particular personal equation. Errors due to this were somewhat eliminated by exchanging observers for a full determination. A network of telegraph longitude stations covering the country was established. In the Longitude Adjustment of 1897, there were 45 stations with 72 links. Ties to Greenwich, Paris, and Brest were included. The average correction to the 72 longitude differences was 0.020 second of time. Many more longitudes had been measured but only those for which the personal equations had been balanced or corrected were used.

Early in this century, experiments were made with a transit micrometer in which the image of the star was tracked with a moving wire. This technique reduced the size of the personal equation,but there remained a tendency for some observers to lead or others to lag behind the moving image. Methods were devised for even measuring these personal equations.

With the development of radio, it was possible to further simplify and also increase the accuracy of longitude determinations. Special time signals were transmitted at short wave frequencies. These have been controlled by the Naval

Observatory and corrected to Greenwich time. At first, the procedure was to broadcast signals for five minutes before the hour. Later, with the improvement of timing techniques, the National Bureau of Standards initiated the transmission of continuous time signals. This has further simplified the observing schedules in the field.

In the present era, as the national geodetic control network nears completion, the need for astronomical determinations has decreased. More concern is given to positioning in a global reference system independent from the deflections of the vertical. Geodetic satellites are providing an accuracy far greater than ever achieved from astronomical observations. For example, the uncertainty of three-dimensional coordinates determined in a present day Doppler network is of the order of a metre. By referencing the geodetic network to such a framework, internal accuracies of the order of one part in 100,000 can be assured. The most recent development is an inertial system which is capable of determining three-dimensional coordinates to an accuracy of the order of 10 centimetres for a series of points between two known points 50 kilometers apart. The daily cost of operation is very high but the speed may make the system competitive with classical survey procedures. This technique belongs more to the future than the past.

I did not include leveling in this review because Ralph Moore Berry presented an excellent paper at our 1976 Spring Convention in Washington and it was published in the June issue of Surveying and Mapping.

COMPUTATIONS

To return to my opening remarks, the justification for classifying surveying as an art must be in its mathematical foundation. A significant part of this is computation. This phase of surveying, then, is my last topic in this bicentennial review.

A few years ago when manufacturers of large computing systems were searching for key phrases to assist in sales promotion, they came upon "Computing is an art." I contend that it always has been and most certainly was in the colonial days. Most of the surveyors of that era were self-taught yet had a better grasp of positional astronomy than the surveyors of today who rely on their "black boxes."

When searching old records, we find evidence of computing in duplicate, using logarithms for complex calculations. Gunter's scales were available when three digits, or an indication of the fourth, would suffice. Crelle multiplication tables were available for the formation and solution of normal equations. The tables had dual three digit entries with six digit products. Instructions were included for "double-precision" or beyond. I recall seeing some of these tables when I entered on duty in the Coast and Geodetic Survey in 1930. They were almost as large as a modern atlas.

One of the first mechanical aids was the Burrough's Adding Machine patented in 1885. Combining this with Crelle could produce sums of cross products at what was then considered to be good speed. In 1895, Otto Steiger of Switzerland devised a mechanical multiplier which was called the Millionaire. It was too large to place on a desk but was placed nearby. It could not accumulate products. These Millionaires, in tandem with adding machines, were the computing aids for much of the work on the adjustment of the Western Half of the 1927 Datum.

By 1930, electro-mechanical desktop calculators were available. Sums of products could be calculated without recording each product. The speed of solving large networks of equations increased, thus the desire to increase the size of networks.

In the 1940's, punched card computers became available. They first operated on electro-magnetic principles and were limited to simple calculations. The story of the rapid development of electronic computing equipment has been fully recorded. Now we carry one in our pocket. We need only state that the surveying community has benefited tremendously and has used such equipment for a better understanding of the mathematical basis of surveying and for a more brilliant display of its art.

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