Surveying

A General Overview

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History

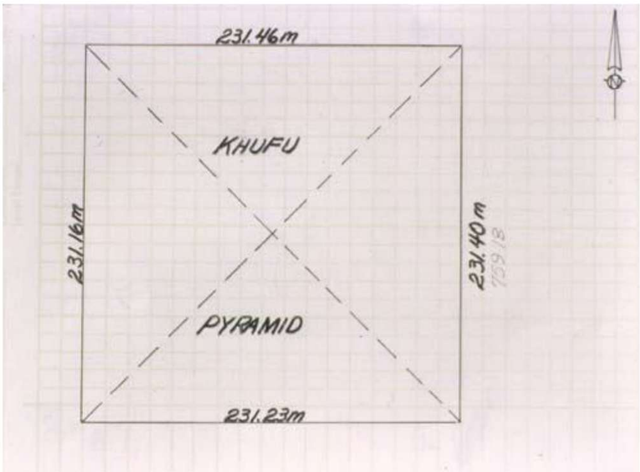
Surveying has been an essential element in the development of the human environment for so many centuries that its importance is often forgotten. It is an imperative requirement in the planning and execution of nearly every form of construction. Surveying was essential at the dawn of history, and some of the most significant scientific discoveries could never have been implemented were it not for the contribution of surveying. Its principal modern uses are in the fields of transportation, building, apportionment of land, and communications.

Except for minor details of technique and the use of one or two minor hand-held instruments, surveying is much the same throughout the world. The methods are a reflection of the instruments, manufactured chiefly in Switzerland, Austria, Great Britain, the United States, Japan, and Germany. Instruments made in Japan are similar to those made in the West.

It is quite probable that surveying had its origin in ancient Egypt. The Great Pyramid of Khufu at Giza was built about 2700 bce, 755 feet (230 metres) long and 481 feet (147 metres) high. Its nearly perfect squareness and north–south orientation affirm the ancient Egyptians' command of surveying.

Evidence of some form of boundary surveying as early as 1400 BCE has been found in the fertile valleys and plains of the Tigris, Euphrates, and Nile rivers. Clay tablets of the Sumerians show records of land measurement and plans of cities and nearby agricultural areas. Boundary stones marking land plots have been preserved. There is a representation of land measurement on the wall of a tomb at Thebes (1400 BCE) showing head and rear chainmen measuring a grainfield with what appears to be a rope with knots or marks at uniform intervals. Other persons are shown. Two are of high estate, according to their clothing, probably a land overseer and an inspector of boundary stones.

There is some evidence that, in addition to a marked cord, wooden rods were used by the Egyptians for distance measurement. There is no record of any angle-measuring instruments of that time, but there was a level consisting of a vertical wooden A-frame with a plumb bob supported at the peak of the A so that its cord hung past an indicator, or index, on the horizontal bar. The index could be properly placed by standing the device on two supports at approximately the same elevation, marking the position of the cord, reversing the A, and making a similar mark. Halfway between the two marks would be the correct place for the index. Thus, with their simple devices, the ancient Egyptians were able to measure land areas, replace property corners lost when the Nile covered the markers with silt during floods, and build the huge pyramids to exact dimensions.



The Greeks used a form of log line for recording the distances run from point to point along the coast while making their slow voyages from the Indus to the Persian Gulf about 325 BCE. The magnetic compass was brought to the West by Arab traders in the 12th century CE. The astrolabe was introduced by the Greeks in the 2nd century BCE. An instrument for measuring the altitudes of stars, or their angle of elevation above the horizon, took the form of a graduated arc suspended from a hand-held cord. A pivoted pointer that moved over the graduations was pointed at the star. The instrument was not used for nautical surveying for several centuries, remaining a scientific aid only.

The Greeks also possibly originated the use of the groma, a device used to establish right angles, but Roman surveyors made it a standard tool. It was made of a horizontal wooden cross pivoted at the middle and supported from above. From the end of each of the four arms hung a plumb bob. By sighting along each pair of plumb bob cords in turn, the right angle could be established. The device could be adjusted to a precise right angle by observing the same angle after turning the device approximately 90°. By shifting one of the cords to take up half the error, a perfect right angle would result.

About 15 BCE the Roman architect and engineer Vitruvius mounted a large wheel of known circumference in a small frame, in much the same fashion as the wheel is mounted on a wheelbarrow; when it was pushed along the ground by hand it automatically dropped a pebble into a container at each revolution, giving a measure of the distance traveled. It was, in effect, the first odometer.

The water level consisted of either a trough or a tube turned upward at the ends and filled with water. At each end there was a sight made of crossed horizontal and vertical slits. When these were lined up just above the water level, the sights determined a level line accurate enough to establish the grades of the Roman aqueducts. In laying out their great road system, the Romans are said to have used the plane table. It consists of a drawing board mounted on a tripod or other stable support and of a straightedge—usually with sights for accurate aim (the alidade) to the objects to be mapped—along which lines are drawn. It was the first device capable of recording or establishing angles. Later adaptations of the plane table had magnetic compasses attached.

Plane tables were in use in Europe in the 16th century, and the principle of graphic triangulation and intersection was practiced by surveyors. In 1615 Willebrord Snell, a Dutch mathematician, measured an arc of meridian by instrumental triangulation. In 1620 the English mathematician Edmund Gunter developed a surveying chain, which was superseded only by the steel tape beginning in the late 19th century.

The study of astronomy resulted in the development of angle-reading devices that were based on arcs of large radii, making such instruments too large for field use. With the publication of logarithmic tables in 1620, portable angle-measuring instruments came into use. They were called topographic instruments, or theodolites. They included pivoted arms for sighting and could be used for measuring both horizontal and vertical angles. Magnetic compasses may have been included on some.

The vernier, an auxiliary scale permitting more accurate readings (1631), the micrometer microscope (1638), telescopic sights (1669), and spirit levels (about 1700) were all incorporated in theodolites by about 1720. Stadia hairs were first applied by James Watt in 1771. The development of the circle-dividing engine about 1775, a device for dividing a circle into degrees with great accuracy, brought one of the greatest advances in surveying methods, as it enabled angle measurements to be made with portable instruments far more accurately than had previously been possible.

Modern surveying can be said to have begun by the late 18th century. One of the most notable early feats of surveyors was the measurement in the 1790s of the meridian from Barcelona, Spain, to Dunkirk, France, by two French engineers, Jean Delambre and Pierre Méchain, to establish the basic unit for the metric system of measurement.

Many improvements and refinements have been incorporated in all the basic surveying instruments. These have resulted in increased accuracy and speed of operations and opened up possibilities for improved methods in the field. In addition to modification of existing instruments.

Modern surveying

Basic control surveys

Geodetic surveys involve such extensive areas that allowance must be made for the Earth’s curvature. Baseline measurements for classical triangulation (the basic survey method that consists of accurately measuring a base line and computing other locations by angle measurement) are therefore reduced to sea-level length to start computations, and corrections are made for spherical excess in the angular determinations. Geodetic operations are classified into four “orders,” according to accuracy, the first-order surveys having the smallest permissible error. Primary triangulation is performed under rigid specifications to assure first-order accuracy.

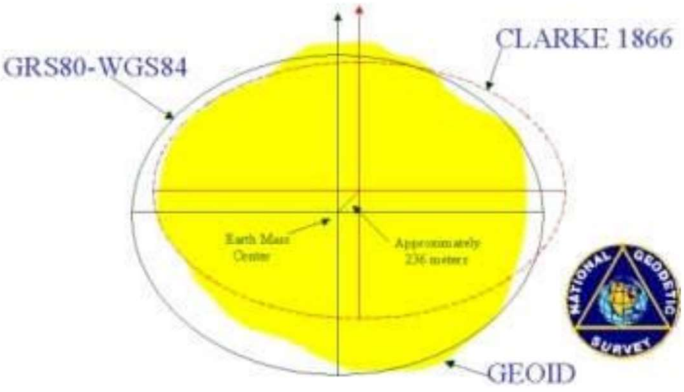
Efforts are now under way to extend and tie together existing continental networks by satellite triangulation so as to facilitate the adjustment of all major geodetic surveys into a single world datum and determine the size and shape of the Earth spheroid with much greater accuracy than heretofore obtained. At the same time, current national networks will be strengthened, while the remaining amount of work to be done may be somewhat reduced. Satellite triangulation became operational in the United States in 1963 with observations by Rebound A-13, launched that year, and some prior work using the Echo 1 and Echo 2 passive reflecting satellites. The first satellite specifically designed for geodetic work, Pageos 1, was launched in 1966.

A first requirement for topographic mapping of a given area is an adequate pattern of horizontal and vertical control points, and an initial step is the assembly of all such existing information. This consists of descriptions of points for which positions (in terms of latitude and longitude) and elevations above mean sea level have been determined. They are occasionally located at some distance from the immediate project, in which case it is necessary to expand from the existing work. This is usually done on second- or third-order standards, depending upon the length of circuits involved.

The accuracy of survey measurements can be improved almost indefinitely but only at increased cost. Accordingly, control surveys are used; these consist of a comparatively few accurate measurements that cover the area of the project and from which short, less accurate measurements are made to the objects to be located. The simplest form of horizontal control is the traverse, which consists of a series of marked stations connected by measured courses and the measured angles between them. When such a series of distances and angles returns to its point of beginning or begins and ends at stations of superior (more accurate) control, it can be checked and the small errors of measurement adjusted for mathematical consistency. By assuming or measuring a direction of one of the courses and rectangular coordinates of one of the stations, the rectangular coordinates of all the stations can be computed.

A system of triangles usually affords superior horizontal control. All of the angles and at least one side (the base) of the triangulation system are measured. Though several arrangements can be used, one of the best is the quadrangle or a chain of quadrangles. Each quadrangle, with its four sides and two diagonals, provides eight angles that are measured. To be geometrically consistent, the angles must satisfy three so-called angle equations and one side equation. That is to say the three angles of each triangle, which add to 180°, must be of such sizes that computation through any set of adjacent triangles within the quadrangles will give the same values for any side. Ideally, the quadrangles should be parallelograms. If the system is connected with previously determined stations, the new system must fit the established measurements.

When the survey encompasses an area large enough for the Earth's curvature to be a factor, an imaginary mathematical representation of the Earth must be employed as a reference surface. A level surface at mean sea level is considered to represent the Earth's size and shape, and this is called the geoid. Because of gravity anomalies, the geoid is irregular; however, it is very nearly the surface generated by an ellipse rotating on its minor axis—*i.e.,* an ellipsoid slightly flattened at the ends, or oblate. Such a figure is called a spheroid. Several have been computed by various authorities; the one usually used as a reference surface by English-speaking nations is (Alexander Ross) Clarke's Spheroid of 1866.



This oblate spheroid has a polar diameter about 27 miles (43 kilometres) less than its diameter at the Equator.

Because the directions of gravity converge toward the geoid, a length of the Earth's surface measured above the geoid must be reduced to its sea-level equivalent—*i.e.,* to that of the geoid. These lengths are assumed to be the distances, measured on the spheroid, between the extended lines of gravity down to the spheroid from the ends of the measured lengths on the actual surface of the Earth. The positions of the survey stations on the Earth's surface are given in spherical coordinates.

Bench marks, or marked points on the Earth's surface, connected by precise leveling constitute the vertical controls of surveying. The elevations of bench marks are given in terms of their heights above a selected level surface called a datum. In large-level surveys the usual datum is the geoid. The elevation taken as zero for the reference datum is the height of mean sea level determined by a series of observations at various points along the seashore taken continuously for a period of 19 years or more. Because mean sea level is not quite the same as the geoid, probably because of ocean currents, in adjusting the level grid for the United States and Canada all heights determined for mean sea level have been held at zero elevation. Because the level surfaces, determined by leveling, are distorted slightly in the area toward the Earth's poles (because of the reduction in centrifugal force and the increase in the force of gravity at higher latitudes), the distances between the surfaces and the geoid do not exactly represent the surfaces' heights from the geoid. To correct these distortions, orthometric corrections must be applied to long lines of levels at high altitudes that have a north–south trend.

Trigonometric leveling often is necessary where accurate elevations are not available or when the elevations of inaccessible points must be determined. From two points of known position and elevation, the horizontal position of the unknown point is found by triangulation, and the vertical angles from the known points are measured. The differences in elevation from each of the known points to the unknown point can be computed trigonometrically.

The National Ocean Service in recent years has hoped to increase the density of horizontal control to the extent that no location in the United States will be farther than 50 miles (80 kilometres) from a primary point, and advances anticipated in analytic photo triangulation suggest that the envisioned density of control may soon suffice insofar as topographic mapping is concerned. Existing densities of control in Britain and much of western Europe are already adequate for mapping and cadastral surveys.

The theodolite

Though for sketch maps the compass or graphic techniques are acceptable for measuring angles, only the theodolite can assure the accuracy required in the framework needed for precise mapping. The theodolite consists of a telescope pivoted around horizontal and vertical axes so that it can measure both horizontal and vertical angles. These angles are read from circles graduated in degrees and smaller intervals of 10 or 20 minutes. The exact position of the index mark (showing the direction of the line of sight) between two of these graduations is measured on both sides of the circle with the aid of a vernier or a micrometer. The accuracy in modern first-order or geodetic instruments, with five-inch glass circles, is approximately one second of arc, or $^{1}/_{3}$,600 of a degree. With such an instrument a sideways movement of the target of one centimetre can be detected at a distance of two kilometres. By repeating the measurement as many as 16 times and averaging the results, horizontal angles can be measured more closely; in geodetic surveying, measurements of all three angles of a triangle are expected to give a sum of 180 degrees within one second of arc.

In the most precise long-distance work, signaling lamps or heliographs reflecting the Sun are used as targets for the theodolite. For less demanding work and work over shorter distances, smaller theodolites with simpler reading systems can be used; targets are commonly striped poles or ranging rods held vertical by an assistant.

An extensive set of these measurements establishes a network of points both on the map, where their positions are plotted by their coordinates, and on the ground, where they are marked by pillars, concrete ground marks, bolts let into the pavement, or wooden pegs of varying degrees of cost and permanence, depending on the importance and accuracy of the framework and the maps to be based on it. Once this framework has been established, the surveyor proceeds to the detail mapping, starting from these ground marks and knowing that their accuracy ensures that the data obtained will fit precisely with similar details obtained elsewhere in the framework.

Global positioning

Techniques used to establish the positions of reference points within an area to be mapped are similar to those used in navigation. In surveying, however, greater accuracy is required, and this is attainable because the observer and the instrument are stationary on the ground instead of in a ship or aircraft that is not only moving but also subject to accelerations, which make it impossible to use a spirit level for accurate measurements of star elevations.

The technique of locating oneself by observations of celestial objects is rapidly going out of date. In practicing it, the surveyor uses a theodolite with a spirit level to measure accurately the elevations of the Sun at different times of the day or of several known stars in different directions. Each observation defines a line on the Earth's surface on which the observer must be located; several such lines give a fix, the accuracy of which is indicated by how closely these lines meet in a point. For longitude it is necessary also to record the Greenwich Mean Time of each observation. This has been obtained since 1884 by using an accurate chronometer that is checked at least once a day against time signals transmitted telegraphically over land lines and submarine cables or broadcast by radio.

A more recent procedure for global positioning relies on satellites, whose locations at any instant are known precisely because they are being continuously observed from a series of stations in all parts of the world. The coordinates of these stations were established by very large scale triangulation based on a combination of radar observations of distances and measurements of the directions of special balloons or flashing satellites, obtained by photographing them at known instants of time against the background of the fixed stars.

The principal method of using satellites for accurate positioning is based on an application of the Doppler effect. A radio signal is transmitted at a steady frequency by the satellite, but a stationary observer detects a higher frequency as the satellite approaches and a lower one as it recedes. The speed of the frequency drop depends on the distance of the observer from the satellite's track, so a determination of this speed provides a measure of that distance. At the instant of the satellite's closest approach, the observed frequency is the same as that transmitted, so at that time the observer must be located somewhere along the line at right angles to the satellite's track. Since this track over the Earth's surface is accurately known at all times, these data define the observer's position.

Establishing the framework

Most surveying frameworks are erected by measuring the angles and the lengths of the sides of a chain of triangles connecting the points fixed by global positioning. The locations of ground features are then determined in relation to these triangles by less accurate and therefore cheaper methods. Establishing the framework ensures that detail surveys conducted at different times or by different surveyors fit together without overlaps or gaps.

For centuries the corners of these triangles have been located on hilltops, each visible from at least two others, at which the angles between the lines joining them are measured; this process is called triangulation. The lengths of one or two of these lines, called bases, are measured with great care; all the other lengths are derived by trigonometric calculations from them and the angles. Rapid checks on the accuracy are provided by measuring all three angles of each triangle, which must add up to 180 degrees.

In small flat areas, working at large scales, it may be easier to measure the lengths of all the sides, using a tape or a chain, rather than the angles between them; this procedure, called trilateration, was impractical over large or hilly areas until the invention of electromagnetic distance measurement (EDM) in the mid-20th century. This procedure has made it possible to measure distances as accurately and easily as angles, by electronically timing the passage of radiation over the distance to be measured; microwaves, which penetrate atmospheric haze, are used for long distances and light or infrared radiation for short ones. In the devices used for EDM, the radiation is either light (generated by a laser or an electric lamp) or an ultrahigh-frequency radio beam. The light beam requires a clear line of sight; the radio beam can penetrate fog, haze, heavy rain, dust, sandstorms, and some foliage. Both types have a transmitter-receiver at one survey station. At the remote station the light type contains a set of corner mirrors; the high-frequency type incorporates a retransmitter (requiring an operator) identical to the transmitter-receiver at the original station. A corner mirror has the shape of the inside of a corner of a cube; it returns light toward the source from whatever angle it is received, within reasonable limits. A retransmitter must be aimed at the transmitter-receiver.

In both types of instrument, the distance is determined by the length of time it takes the radio or light beam to travel to the target and back. The elapsed time is determined by the shift in phase of a modulating signal superimposed on the carrier beam. Electronic circuitry detects this phase shift and converts it to units of time; the use of more than one modulating frequency eliminates ambiguities that could arise if only a single frequency had been employed.

EDM has greatly simplified an alternative technique, called traversing, for establishing a framework. In traversing, the surveyor measures a succession of distances and the angles between them, usually along a traveled route or a stream. Before EDM was available, traversing was used only in flat or forested areas where triangulation was impossible. Measuring all the distances by tape or chain was tedious and slow, particularly if great accuracy was required, and no check was obtainable until the traverse closed, either on itself or between two points already fixed by triangulation or by astronomical observations.

In both triangulation and traversing, the slope of each measured line must be allowed for so that the map can be reduced to the horizontal and referred to sea level. A measuring tape may be stretched along the ground or suspended between two tripods; in precise work corrections must be applied for the sag, for tension, and for temperature if these differ from the values at which the tape was standardized. In work of the highest order, known as geodetic, the errors must be kept to one millimetre in a kilometre, that is, one part in 1,000,000.

A total station is an electronic-optical instrument used in modern surveying and building construction.

The total station is an electronic theodolite (transit) integrated with an electronic distance meter (EDM) to read slope distances from the instrument to a particular point.

Robotic total stations allow the operator to control the instrument from a distance via remote control. This eliminates the need for an assistant staff member as the operator holds the reflector and controls the total station from the observed point.

Detail surveying

The actual depiction of the features to be shown on the map can be performed either on the ground or, since the invention of photography, aviation, and rocketry, by interpretation of aerial photographs and satellite images. On the ground the framework is dissected into even smaller areas as the surveyor moves from one point to another, fixing further points on the features from each position by combinations of angle and distance measurement and finally sketching the features between them freehand. In complicated terrain this operation can be slow and inaccurate, as can be seen by comparing maps made on the ground with those made subsequently from aerial photographs.

Ground survey still has to be used, however, for some purposes; for example, in areas where aerial photographs are hard to get; under the canopy of a forest, where the shape of the ground—not that of the treetops—is required; in very large scale work or close contouring; or if the features to be mapped are not easily identifiable on the aerial photographs, as is the case with property boundaries or zones of transition between different types of soil or vegetation. One of two fundamental differences between ground and air survey is that, as already mentioned, the ground survey interpolates, or sketches, between fixed points, while air survey, using semiautomatic instruments, can trace the features continuously, once the positions of the photographs are known. One effect of this is to show features in uniform detail rather than along short stretches between the points fixed in a ground survey.

The second difference is that in ground survey different techniques and accuracies may be adopted for the horizontal and vertical measurements, the latter usually being more precise. Accurate determinations of heights are required for engineering and planning maps, for example, for railway gradients or particularly for irrigation or drainage networks, since water in open channels does not run uphill.

The methods used for fixing locations within the horizontal detail framework are similar to, but less accurate than, those used for the primary framework. Angles may be measured with a hand-held prismatic compass or graphically with a plane table, or they may be estimated as right angles in the case of points that are offset by short distances from straight lines between points already fixed. Detail points may be located by their distances from two fixed points or by distance and bearing from only one.

The surveyor may record measurements made in the field and plot them there on a sketch board or in the office afterward, but if the country is open and hilly, or even mountainous, the plane table offers the best way of recording the data. A disadvantage of plane-table work is that it cannot be checked in the office, and so it requires greater intelligence and integrity of the surveyor.

The plane table reached its most efficient form of use in the Survey of India, begun in 1800, in which large areas were mapped with it by dedicated Indian surveyors. It consists of a flat board that is mounted on a tripod so that it can be fixed or rotated around a vertical axis. It is set up over a framework point or one end of a measured baseline with its surface (which is covered with paper or other drawing medium) horizontal. It is turned until the line joining its location with another framework point or the other end of the baseline is parallel to the same line as drawn on the paper. This alignment is performed with the aid of an alidade, or sight rule, a straightedge fitted with simple sights. The alidade is then directed toward points on features that are to be fixed, and pencil rays are drawn along the sight rule toward them. The procedure is repeated at the other framework point or the other end of the baseline; the points where the rays intersect on the table will be the map positions of the features.

In surveying for engineering projects, more sophisticated instruments are employed to maximize accuracy. For example, distances may be measured by EDM or by tachymetry, a geometric technique in which the vertical distance on a graduated vertical staff, seen between two stadia hairs in the theodolite eyepiece, is a measure of the horizontal distance between the theodolite and the staff—usually 100 times the difference between the two readings. This method requires at least one assistant to move the staff from place to place. Modern surveying instruments combine a theodolite, EDM equipment, and a computer that records all the observations and calculates the height differences obtained by measuring vertical angles.

Aerial surveying

Aviation and photography have revolutionized detailed mapping of features visible from the air. An aerial photograph, however, is not a map. In the case of the House of Parliament and Westminster Bridge, London, for example, the tops of the towers would coincide with the corners of the foundations when mapped. In an aerial photograph, however, they would not, being displaced radially from the centre. An important property of vertical aerial photographs is that angles are correctly represented at their centres, but only there. Similar distortions are present in photographs of hilly ground. This problem may be dealt with in two principal ways, depending on the relative scales of the map and the photographs and on whether contours are required on the map. The older method, adequate for planimetric maps at scales smaller than the photographs, was used extensively during and after World War II to map large areas of desert and thinly populated country; mountainous areas could be sketched in, but the relief was not accurately shown.

As in ground survey, a framework of identified points is necessary before detailed mapping can be carried out from the air. The photographs are ordinarily taken by a vertically aligned camera in a series of strips in which each picture overlaps about 60 percent of the preceding one; adjacent strips overlap only slightly. The overlaps make it possible to assemble a low-order framework or control system based on small, recognizable features that appear in more than one photograph. In the simplest form of this procedure each photograph is replaced by a transparent template on which rays are drawn (or slots are cut) from the centre of the picture to the selected features. The angles between these rays or slots are correct, and slotted templates can be fitted together by inserting studs, which represent the features, into the appropriate slots and sliding the templates so that each stud engages the slots in all the pictures showing the corresponding feature. This operation ensures that the centres of the pictures and the selected features are in the correct relationship. The array of overlapping photographs can be expanded or contracted by sliding them about on the work surface as long as the studs remain engaged in the slots, so the assemblage can be positioned, oriented, and scaled by fitting it to at least two—preferably several—ground-control points identified on different photographs.

This technique may be extended by using two additional cameras, one on each side, aimed at right angles to the line of flight and 30 degrees below the horizontal. The photographs taken by the side cameras overlap those taken by the vertical one and also include the horizon; the effect is to widen the strip of ground covered and thus to reduce the amount of flying required. Points in the backgrounds of the oblique photographs can be incorporated in the overlapping array as before to tie the adjacent flight paths together. Photography from high-flying jet aircraft and satellites has rendered this technique obsolete, but before those advances took place it greatly facilitated the mapping of underdeveloped areas.

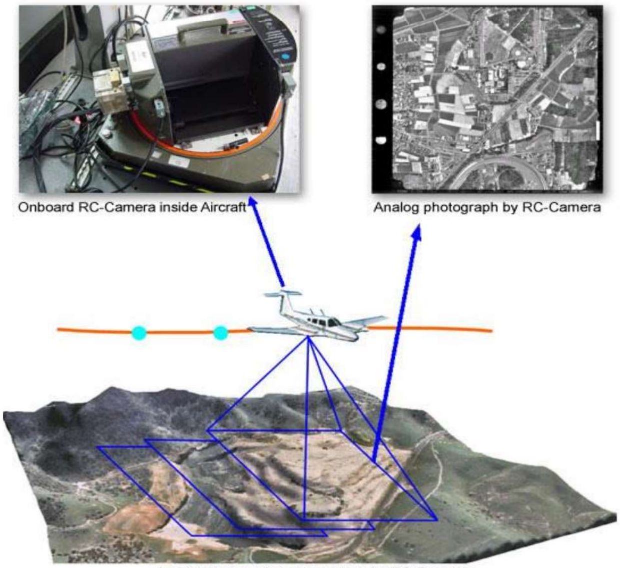
the production of maps with accurate contours at scales five or six times that of the photographs, a more sophisticated approach is necessary. The ground-survey effort must be expanded to provide the heights as well as the positions of all the features employed to establish the framework.

In this technique the details within each segment of the map are based not on individual photographs but on the overlap between two successive ones in the same strip, proceeding from the positions and heights of features in the corners of each area. A three-dimensional model can be created by viewing each pair of consecutive photographs in a stereoscope; by manipulation of a specially designed plotting instrument, the overlapping area can be correctly positioned, scaled, and oriented, and elevations of points within it can be derived from those of the four corner points. These photogrammetric plotting instruments can take several forms. In projection instruments the photographs are projected onto a table in different colours so that, through spectacles with lenses of complementary colours, each eye sees only one image, and the operator visualizes a three-dimensional model of the ground. A table or platen, with a lighted spot in the middle, can be moved around the model and raised or lowered so that the spot appears to touch the ground while the operator scans any feature, even if it is located on a steep hillside. A pencil directly beneath the spot then plots the exact shape and position of the feature on the map. For contouring the platen is fixed at the selected height (at a scale adjusted to that of the model), and the spot is permitted to touch the model surface wherever it will; the pencil then draws the contour.

With more complex mechanical devices, rays of light reaching the aircraft taking the two photographs are represented by rods meeting at a point that represents the position of the feature of the model being viewed. With a complicated system of prisms and lenses the operator, as with projection instruments, sees a spot that can be moved anywhere in the overlap and up or down to touch the model surface, as described above. A mechanical or electronic system moves a pencil into the corresponding position on a plotting table to which the map manuscript is fixed.

With computerized analytic instruments the mechanical operation is limited to measuring coordinates on the two photographs, and the conversion to a three-dimensional model is performed entirely by the computer. It is possible with the most precise plotting instruments of either type to draw a map at four to six times the scale of the photographs and to plot contours accurately at a vertical interval of about one one-thousandth of the height from which the photographs were taken. With such analytic instruments the record can be stored in digital as well as graphic form to be plotted later at any convenient scale.

All these methods produce a line or drawn map; some of them also create a data file on disk or tape, containing the coordinates of all the lines and other features on the map. On the other hand, aerial photographs can be combined and printed directly to form a photomap. For flat areas this operation requires simply cutting and pasting the photographs together into a mosaic. For greater accuracy the centres of the photographs may be aligned by the use of slotted templates as described above to produce a photomap called a controlled mosaic.



A general view of photographing by RC-Camera

A much more precise technique is based on the use of an orthophoto scope. With this device, overlapping photographs are employed just as in the stereoscopic plotter already described, but the instrument, rather than the manual tracing of the features and contours, scans the overlap and produces an orthophotograph by dividing the area into small sections, each of which is correctly scaled. This procedure is best applied to areas of low relief without tall buildings; the resulting maps can then be substituted for line maps in rural areas where they are particularly useful in planning resettlement in agricultural projects. Because no fair drawing is required, the final printed map can be produced much more quickly and cheaply than would otherwise be possible.